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INVESTIGATION OF SPRAY-APPLIED POLYURETHANE FOAM ROOFING SYSTEM--ETC(U)
JUL 77 R L ALUMBAUGH, J R KEETON

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An experimental investigation of the performance and properties of spray-applied polyurethane foam roofing systems is described. Polyurethane foam studied included densities of 2.0 and 2.5 pcf. Elastomeric coating systems included catalyzed silicone, moisture-curing silicone, butyl-hypalon, neoprene-hypalon, hypalon, butyl, chlorinated rubber, catalyzed urethane, moisture-curing urethane, and an acrylic emulsion. In addition, a fibrated aluminum-asphalt was included. Properties of the coating systems (continued) over

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such as adhesion, tensile strength, elongation, impact, and wind-driven-rain absorption are also reported. Experimental roofing panels were located at a seashore site, a desert site, and a cold weather site. After exposure periods of up to two years, performance of the silicones and the catalyzed urethane was rated as excellent at all three sites. Rankings based on the laboratory tests showed a catalyzed urethane as first, followed by the silicones and a neoprene-hypalon. Adhesion characteristics of coatings applied to foam which had been allowed to degrade for periods up to 9 days prior to coating application are also reported. Noticeable loss of adhesion was observed in the panels in which the foam had been allowed to degrade for 3 days or more prior to coating.

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CONTENTS

BACKGROUND

Over the past several years, maintenance of roofs and roofing systems has become an ever-increasing problem. The problem has been compounded by changes in composition of bitumen and felts, by materials shortages, by poor workmanship, and by other factors which lead to poor performance and short service life of these waterproofing systems. Information available at the Civil Engineering Laboratory (CEL) for FY74 indicates that the annual maintenance cost for roofs at Naval Shore Activities was about 11 million dollars, representing almost three percent of the total Naval Shore Activities maintenance costs.

Because of the increasing seriousness of the roof maintenance problem, CEL was requested by the Naval Facilities Engineering Command (NAVFAC) to investigate roofing systems under YF 54.593.011.01.001, "Investigation of Roofing Systems for Maintenance of Naval Shore Structures." This research was to be directed toward all areas of roofing problems. The objective of the investigation was to provide a significant reduction in maintenance costs for roofing systems at Naval Shore Bases by defining existing problems and identifying conventional and new materials and methods that might eliminate or alleviate these problems. An extensive survey of Naval Shore Bases was conducted in different climatic areas to define and delineate their most recent roofing problems.

The experimental program was to cover a broad spectrum of roofing problem areas that were either known or would be delineated by the roofing survey. In pursuing this aspect of the program, funds were provided to the National Bureau of Standards (NBS) to develop a comprehensive research program for determining the effect of moisture on built-up roofs (BUR). The draft of a report including a state-of-the-art summary and the description of a proposed research program is currently being revised by NBS. In addition to this contractual effort covering the effect of moisture on BUR's, support was also provided to the U.S. Bureau of Reclamation (USBR) Research Laboratories to aid in their preparation of a report on an extensive research effort which USBR had conducted earlier in new roofing systems [1].

Early in the CEL roofing research program, NAVFAC requested that the Laboratory cooperate with the Northern Division of NAVFAC (NORNAVFAC) to develop and carry out an experimental field investigation of spray-applied polyurethane foam (PUF) roofing systems at the Naval Reserve Center (NRC), Clifton, New Jersey. Initial results of this investigation are presented in Reference 2. Because of the requirement to assist in the development of plans for the experimental field investigations of PUF roofing systems, the original experimental roofing investigations at

CEL were directed toward (1) PUF materials and (2) coatings for protecting PUF from weathering. These investigations took on added significance because of the requirement in the DOD Construction Criteria Manual (1972) that all new roofs have a "U" value of 0.05 $Btu/(hr)(ft^2)(^oF)$ [3].

INTRODUCTION

Over the past 15 years, spray-applied PUF has been utilized in roofing systems in ever-increasing quantities. The fact that this usage continues to increase significantly is indicative of its acceptance in many areas. However, as with any new material, this utilization has not been without problems. Perhaps the biggest fallacy that must be overcome is that PUF roofing systems are cure-alls for each and every roofing problem. Unfortunately, during the initial years of their use, PUF roofing systems were often proclaimed, by contractors and material suppliers alike, to be a panacea for all roofing problems. As with any new material, much needed to be learned about these systems, and time was required for proper experience to be gained by those in the industry.

The most important factor is that PUF materials degrade rapidly when exposed to sunlight and thus must be protected. During the early years, many different coating systems were used to achieve this protection and, as might be expected, the main criterion often was "the cheaper, the better." Little time was required, however, to learn that just any coating system would not provide the proper protection. It was found that many coating systems that performed well when applied to other substrates would crack and flake from a foam surface within 6 to 18 months, thus exposing unprotected foam to sunlight. It soon became obvious that only an elastomeric type of coating system has the flexibility, elongation, and tensile strength required to accommodate the rather large expansion and contraction inherent in spray-applied PUF when subjected to ambient thermal cycling.

Because of their lower compressive and tensile strengths, PUF materials are more susceptible to physical abuse than many conventional roofing materials. As a result, roofing contractors, maintenance personnel, and others who walk or work on PUF roofing systems must learn to treat such roofs with the proper respect in order to prevent or minimize mechanical damage.

As with other roofing systems, PUF materials must be applied to properly prepared substrates or roof decks. Application over a water-soaked BUR system or over a surface that is dirty or covered with a weathered, chalky paint system would be doomed to failure. This would be true regardless of whether the roofing maintenance system being applied was PUF or any other maintenance system.

Finally, spray-applied PUF has a somewhat uneven surface at best and, if improperly applied, can have a very rough surface texture called "popcorn" or "treebark". Not only is the texture of such foam quite

rough, but the physical characteristics of the foam itself are frequently inferior. The quality of surface texture that can be obtained is largely a function of the skill of the foam spray operator, including his ability to properly adjust the spray equipment. Popcorn or treebark surfaces on a PUF roof are completely unacceptable, because they are very difficult to coat properly. Since coatings tend to flow from high areas into low areas, the high points do not have sufficient minimum thickness, leading to rapid deterioration of the PUF roofing system.

In the early days of PUF roof systems, shaving of the foam surface was accomplished with a special machine. This provided a smoother surface for the coating but the shaving action exposed the cell structure of the foam. In addition, the protective coating system was required to bridge the open cell structure, which greatly reduced the bonding surface for the coating. The exposed cell structure also tended to promote pinholing in a coating placed over it, providing focal points for failure of the coating system. For these reasons, such a procedure is not recommended.

A direct result of these potential problems with PUF roofing systems was that many reliable roofing contractors were in and out of the spray-applied PUF roofing business rather rapidly. Since there seemed to be no solution for some of these problems, CEL decided to concentrate its research on spray-applied PUF roof systems. The objective of the research was to generate data which will provide guidelines for coating systems to protect PUF materials used in a roof system.

EXPERIMENTAL

Selection of Materials

As noted above, the primary emphasis in this investigation is directed toward determining requirements for good protective coating systems for spray-applied PUF materials. In addition, but to a much more limited extent, foam characteristics are also being investigated.

Spray-Applied PUF Materials. At about the time this investigation was being initiated, the National Bureau of Standards (NBS) completed a report, "Guidelines for Selection of and Use of Foam Polyurethane Roofing Systems" [4]. In preparing plans and selecting materials for the field investigation at NRC, Clifton, New Jersey, CEL had conducted a state-of-the-art survey of materials and methods for application of PUF roofing systems. Information obtained in this survey together with the criteria set forth in Reference 4 were used in selecting the spray-applied PUF material. In order to minimize the number of variables, the products of only one PUF manufacturer were utilized. However, to provide some variability, foam densities of 2.0 pcf and 2.5 pcf were included. The foams selected were CPR 485 (2 pcf) and CPR 485-2.5 (2.5 pcf), products of CPR Division of Upjohn Company. These materials were readily available and widely used throughout the country.

Elastomeric Coating Systems. During the state-of-the-art survey it was determined that a number of different generic types of coating systems had already been found to be unsatisfactory for protecting PUF materials against weathering. These types included coatings that were thin in consistency and of a brittle nature. It was also found that only elastomeric coating systems performed well when applied over PUF. For this reason, with one exception, the only protective coating systems included in this investigation are those designed for use on foam, i.e., with rubber-like or elastomeric characteristics. The exception was a high quality fibrated aluminum-pigmented asphalt. This was included as a "control" since aluminum-asphalts or unpigmented asphalt coatings appeared to be among the most widely used coating systems over PUF materials even though their performance record was poor.

Most of the different generic types of elastomeric coating systems that appeared to have merit for protecting spray-applied PUF materials were included in this investigation. An additional consideration in this selection was the permeability of the coating system. There is quite a controversy in the industry over whether (1) "permeable" or "breathing" or (2) "impermeable" or "nonbreathing" coatings generally perform best as protective coatings for foam. Although there are no firm data supporting a case for either type, it would appear that both are useful under certain conditions. Actually, all of the coatings are permeable to a certain amount of moisture vapor but vary in their degree of permeability. For purposes of this report, coatings systems with ratings (ASTM Designation E 96-66) of (1) less than 0.1 perms are considered vapor impermeable, (2) 0.1 to 1.0 perms are considered moderately vapor permeable, and (3) greater than 1 perm are considered vapor permeable. A listing of the systems investigated, including their permeability category, is shown below:

System Number	Description
1	Catalyzed silicone rubber — vapor permeable
2	Moisture-cured silicone rubber — vapor permeable
3	Catalyzed butyl-hypalon — vapor impermeable
4	Catalyzed butyl-hypalon — vapor impermeable
5	Hypalon mastic — vapor impermeable
6	Elastomeric acrylic emulsion — vapor permeable
7	Neoprene-hypalon — moderately vapor permeable
8	Aluminum-filled, catalyzed butyl — vapor impermeable
9	Catalyzed butyl-hypalon — vapor impermeable

System Number	Description
10	Aluminum-filled, catalyzed urethane — moderately vapor permeable
11	Chlorinated rubber — moderately vapor permeable
12	Hypalon mastic — vapor impermeable
13	Catalyzed urethane — vapor permeable
14	Moisture-cured urethane — vapor permeable
15	Fibrated aluminum-pigmented asphalt — vapor impermeable

As indicated above, the protective coating systems investigated included two silicone rubbers, three butyl-hypalons, one neoprene-hypalon, one aluminum-pigmented butyl, two hypalon mastics, one chlorinated rubber, three urethane elastomers, one elastomeric acrylic emulsion, and, as a control, one fibrated aluminum-asphalt. More detailed descriptions of these coating materials are given later in this report.

Field Investigations

In order to determine the performance characteristics of the various elastomeric coated PUF roofing systems, plywood panels were sprayed with PUF, coated, and exposed at three different experimental field weathering sites. Periodically, these experimental panels are inspected and photographed, and preselected specimens are removed and returned to the laboratory for additional study.

Preparation of Experimental Panels. Specimen panels were constructed from one-half inch plywood cut to a 2 foot by 4 foot size. Two 2 x 4's were secured across the two-foot width of the panels for later use in attaching the experimental panels to the exposure racks. The surface onto which the foam was to be sprayed was then primed with one coat of asphalt roof primer, Federal Specification SS-A-701a, applied at the rate of 250 square feet per gallon. The spray-applied primer was allowed to cure for three to four weeks prior to foaming in order to permit evaporation of solvents that might affect adhesion of the foam. After drying, the back side of the panels and any other exposed wooden surfaces were painted to protect them from weathering.

Following proper curing of the primer, the PUF was spray-applied to the primed surface using a Gusmer Model FF unit. Application was in either two or three lifts to provide approximately 1-1/2 inches of PUF. This gave about 3 square feet of foam per pound of the liquid urethane components. The technicians applying the foam exercised great care in properly adjusting the foaming equipment in order to obtain quality foam surfaces, i.e., surfaces as smooth as possible. Very rough surfaced foam, such as popcorn or treebark, was not acceptable, and any panels having such surfaces were discarded.

Most of the systems utilized PUF with a density of 2 pcf. However, in a few cases, the PUF density was 2.5 pcf. Except where otherwise noted, PUF with a density of 2 pcf was used. In a few others, duplicate panels were prepared using both densities of foam.

Four panels to be coated were prepared for each of the systems. Three of these were intended for long term exposure at the three experimental sites and the fourth was used to determine selected properties after various periods of weathering at Port Hueneme. In addition, several panels of both densities of PUF were prepared which were to remain uncoated. Several panels were prepared at the same time. They were then covered with black plastic to protect them from sunlight and from exposure to moisture or fumes until they were coated or placed on exposure.

A detailed description of the coating systems and their application is given below and tabulated in Table 1. Trade names and sources of the materials are listed in Appendix A. Each of the coating materials was given a cursory analysis and these results are presented in Appendix B.

Coating coverage and thicknesses were determined by spraying the systems on steel panels prior to and during application of the coatings to the foam. Coverage was determined by measuring the wet film thickness with a wet film thickness gage, and dry film thickness was later determined using a magnetic thickness gage. Dry film thicknesses listed in Table 1 were primarily determined with a Peak Scale Lupe on samples cut from the coated foam. Unless noted otherwise, the coating systems were easily applied with a 30-to-1 airless spray unit.

System 1 — Catalyzed Silicone Rubber. This system consisted of one coat of medium-gray, catalyzed silicone rubber base coat, and one coat of a cement-gray, catalyzed silicone rubber topcoat. The total system yielded a nominal dry film thickness of 20.5 mils. Because of the short pot life of the catalyzed system, application requires a special unit in which the two compounds are mixed in the spray gun just prior to leaving the nozzle. To obtain a proper cure, correct metering of the two components by the spray apparatus is critical, and calibration of the equipment was necessary prior to applying each of the two coats. Since CEL did not have such equipment available, these silicone coatings were applied by a contractor licensed by the coating manufacturer. The base coat was allowed to cure about 2 hours before applying the topcoat. This coating system is referred to as breathing or vapor permeable because it allows passage of moisture vapor but not liquid water.

System 1G — Catalyzed Silicone Rubber With Granules. This system is identical to System 1 except that gray ceramic roofing granules were broadcast into the wet topcoat at the rate of $1/2\ lb/ft^2$. The granules are intended to provide a longer-wearing, more durable surface that is more resistant to weathering, damage by foot traffic, and bird pecking. Total system dry film thickness was 20.5 mils.

System 2 — Moisture-Curing Silicone Rubber. This system consisted of two coats of a single-component moisture-curing silicone rubber. The recommended application rate for the light gray base coat and the white topcoat, identical except for color, was 1 gal/100 ft^2. Such a coverage should yield a total average dry film thickness of 15 mils, somewhat less than the 23.5 mils actually obtained. The light gray base coat was permitted to cure overnight prior to applying the white topcoat. Both of these one-part materials were easily applied with conventional airless spray equipment. However, because the proper tip was not available at the time the coatings were applied, a larger tip was used. As a result, not enough solvent was volatilized during the spray operation and a number of cracks occurred in the low spots on the panels. For this reason, a second set of panels was prepared. This coating system was also a vapor permeable coating.

System 2A — Moisture-Curing Silicone Rubber. This system was the same as System 2 except that it was applied over PUF with a density of 2.5 pcf, using the recommended smaller tip. The application rate was 1 gal/100 ft^2 per coat and the total system nominal dry film thickness was 16 mils.

System 3 — Catalyzed Butyl-Hypalon. This system consisted of one coat of a black catalyzed butyl base coat and one coat of white catalyzed hypalon topcoat. The two components of both the base coat and topcoat were mixed prior to application* with a conventional airless spray unit and both were applied within 15 minutes after mixing. Application rate for the black butyl base coat and white hypalon topcoat was 2 gal/100 ft^2 and 1-1/2 gal/100 ft^2, respectively, giving a total nominal system dry film thickness of 18 mils. This butyl-hypalon system is a nonbreathing or vapor impermeable coating which inhibits passage of both water vapor and liquid water.

Systems 4 and 4A — Catalyzed Butyl-Hypalon. These systems consisted of a base coat of a two-component cationically-polymerized tan butyl and a topcoat of a one-component white hypalon applied at a rate of 2-1/2 gal/100 ft^2 and 1 gal/100 ft^2, respectively. System dry film thickness was 21.0 mils, slightly less than the recommended total system dry film thickness of 22.5 mils. These butyl-hypalon systems are also classed as vapor impermeable. The protective coatings of System 4 were partially damaged in transit to the test sites and, as a result, System 4A was prepared. This system is essentially identical to System 4 except that it was applied over 2.5 pcf foam. Total dry film thickness was 21 mils.

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* The manufacturer recommends application of the black butyl coating using a special spray apparatus that mixes the two components just prior to leaving the gun. However, they stated that the two components could be mixed prior to spraying if applied within 15 minutes after mixing.

System 5 — Hypalon Mastic. This one-coat system consisted of a single-component, white hypalon mastic. Recommended application rate is 6 gal/100 ft^2 which should give a minimum dry film thickness of 30 mils. The average 16.5 mil thickness obtained on these panels was only slightly more than half of the recommended thickness. This mastic material is very thixotropic and difficult to spray properly, even with the 40-to-1 ratio airless spray and line heaters that are recommended. Because this equipment was not available at CEL, the coating manufacturer arranged for a roofing contractor to coat the panels. This system provides a vapor impermeable film.

Systems 6 and 6A — Elastomeric Acrylic Emulsion. Panels coated with this white, single-component elastomeric emulsion consisted of either one coat (System 6A) or two coats (System 6). Application at the approximate rate of 2-1/2 gal/100 ft^2 in one coat (6A) gave a nominal dry film thickness of 34 mils. However, at this thickness, very minute checking of the film occurred in the small depressed areas all over the panel. As a result, a second set of panels was prepared on which the material was applied in two coats instead of one coat. The two-coat system of this material resulted in a total system average dry film thickness of 41 mils, with no checking. This acrylic emulsion is a vapor permeable coating.

System 7 — Neoprene-Hypalon. This system consisted of a single-component, black neoprene base coat applied at the rate of 4 gal/100 ft^2 and a single-component white hypalon topcoat applied at 2 gal/per 100 ft^2. The neoprene coating was applied as one fog coat and two full coats while the hypalon was applied as two full coats. This gave a total system nominal dry film thickness of 22 mils. This neoprene-hypalon coating system is classed as a moderately vapor permeable.

Systems 8 and 8A — Aluminum-Pigmented Catalyzed Butyl. Systems 8 and 8A consisted of two identical coats of aluminum-pigmented, two-component butyl, with each coat applied at a rate of 1-1/2 gal/100 ft. The two components of the butyl were thoroughly mixed prior to the spray application. Total nominal dry film thickness was 26 mils. System 8, which was applied over 2 pcf foam was partially damaged during transport to the test sites. System 8A, identical to System 8, was applied over 2.5 pcf foam and both systems were exposed at the test sites. This butyl system produces a vapor impermeable film.

System 9 — Catalyzed Butyl-Hypalon. This system consisted of a base coat of catalyzed black butyl followed by a topcoat of single-component white hypalon. The two components of the butyl were mixed prior to spraying, and the application rate was 2 gal/100 ft^2. The hypalon, applied at the rate of 2 gal/100 ft^2, provided a total system nominal dry film thickness of 22 mils. This coating provides a vapor impermeable film.

System 10 — Aluminum-Pigmented Catalyzed Urethane Elastomer. One coat of catalyzed, aluminum-pigmented urethane elastomer was applied at the rate of 2-1/2 to 3 gal/100 ft^2 and provided a total nominal dry film thickness of 26 mils. The two components were mixed prior to application. This elastomeric coating tended to flow toward low areas on the panels and "puddle" therein, causing rather thin coverage of the high points of the foam. This system is a moderately vapor permeable material.

System 11 — Chlorinated Rubber. This system consisted of two coats of a single-component chlorinated rubber applied at the rate of 2 gal/100 ft^2 per coat to yield a total system nominal dry film thickness of 26 mils. The two coats were of different color to facilitate complete coverage by the second coat but otherwise were identical. This system provided a moderately vapor permeable film.

Systems 12 and 12A — Hypalon Mastic. Two identical coats of white, single-component hypalon mastic were spray-applied to the foamed panels at the rate of 2 gal/100 ft^2 per coat to give a nominal total system dry film thickness of 33 (System 12) and 29 (System 12A) mils. This coating was rather thixotropic and difficult to apply using a 30-to-1 ratio airless spray. As a result, the film applied as System 12 was somewhat less than optimum. In a second application over 2.5 pcf foam (System 12A), a container heater was used to warm the temperature of the material after thinning at the rate of 1 pint of thinner per 5 gallons of hypalon. This combination made the material less thixotropic and it sprayed very well with a 30-to-1 ratio airless spray. This system gives a vapor impermeable film.

System 13 — Catalyzed Urethane Elastomer. This system consisted of one coat of a catalyzed, aluminum-pigmented urethane base coat applied at the rate of 2 gal/100 ft^2 and one coat of catalyzed white aliphatic urethane topcoat applied at the rate of 1 gal/100 ft^2. This provided a total nominal system dry film thickness of 23.5 mils. The two components of both the base coat and the topcoat were thoroughly mixed prior to application. This system provides a vapor permeable film.

Systems 14 and 14A — Moisture-Curing Urethane Elastomer. This consisted of a single-component, gray urethane coating that cures by reacting with moisture in the air and by solvent evaporation. System 14 was applied in one coat at the rate of 3 gal/100 ft^2 to give a nominal dry film thickness of 42 mils. Application with the 30-to-1 ratio airless spray was very difficult in that a proper fan could not be obtained. This resulted in a very nonuniform, poor quality film. Application of this urethane coating as System 14A was accomplished over 2.5 pcf foam in two coats after thinning at the rate of 1 pint of thinner per 5 gallons of coating. This gave a good fan and a very uniform film at total nominal dry film thickness of 39 mils. This system is a vapor permeable coating film.

System 15 — Fibrated Aluminum-Asphalt. This system applied over 2.5 pcf foam, consisted of one coat of a single-component fibrated asphalt applied at the rate of 3 gal/100 ft^2 and 1 coat of a single-component fibrated aluminum-asphalt applied at the recommended rate of 2 gal/100 ft^2. Total nominal dry film thickness was 44 mils. This system is vapor impermeable.

Exposure Sites. One panel of each of the systems described above was placed on exposure at each of three experimental weathering sites. The sites were carefully selected to provide different weathering conditions. The three experimental sites are described below. Panels are inclined at a slope of about 3.5 in 12.

Marine Seashore Site — Port Hueneme, California. This site is a temperate marine atmosphere located along the coast about 60 miles northwest of Los Angeles. The experimental weathering racks shown in Figure 1 are located approximately 200 yards from the surf at an elevation of about 10 feet above sea level.

Desert Site — China Lake, California. This site is a dry, high desert area located about 125 miles northeast of Los Angeles. The exposure racks, shown in Figure 2, are situated on one of the test ranges at the Naval Weapons Center (NWC), China Lake, California, at an elevation of 2,440 feet.

Cold Weather Site — Pickel Meadows, California. This site is located at the Marine Corps Mountain Warfare Training Center, Pickel Meadows, California (MCMWTC). This activity is located in the Sierra Nevada mountains about 18 miles west of Bridgeport, California at an elevation of 7,000 feet. Racks are shown in Figure 3.

Average monthly weather data for all three test sites, including temperature and precipitation, are given in Appendix C for the period that the PUF roofing panels have been exposed.

Performance Characteristics. The performance characteristics of the coated PUF roofing systems were determined at periodic intervals (about 6 months, 1 year, 18 months, and 2 years) by visual inspections and ratings and by photomacrographic studies. In addition, physical measurements were made on the uncoated control panels to determine the extent to which the foam degrades with time.

Visual Inspections and Ratings. The visual inspections consist of a careful study and rating of the performance characteristics of the coated PUF panels. Since the first signs of deteriorLation of the PUF Roofing Systems normally occur in the coatings, the various factors considered relate primarily to coating performance. The performance characteristics that were considered included adhesion, blistering, checking, cohesion, cracking, flaking, peeling, pinholing, and hail damage. Where applicable, performance characteristics covered by ASTM Photographic Reference Standards were used in assigning ratings to the individual characteristics. All of these factors were then considered in assigning the overall performance ratings presented in this report. Ratings were assigned as follows:

Figure 1. Experimental panels at seashore site, Port Hueneme, California.

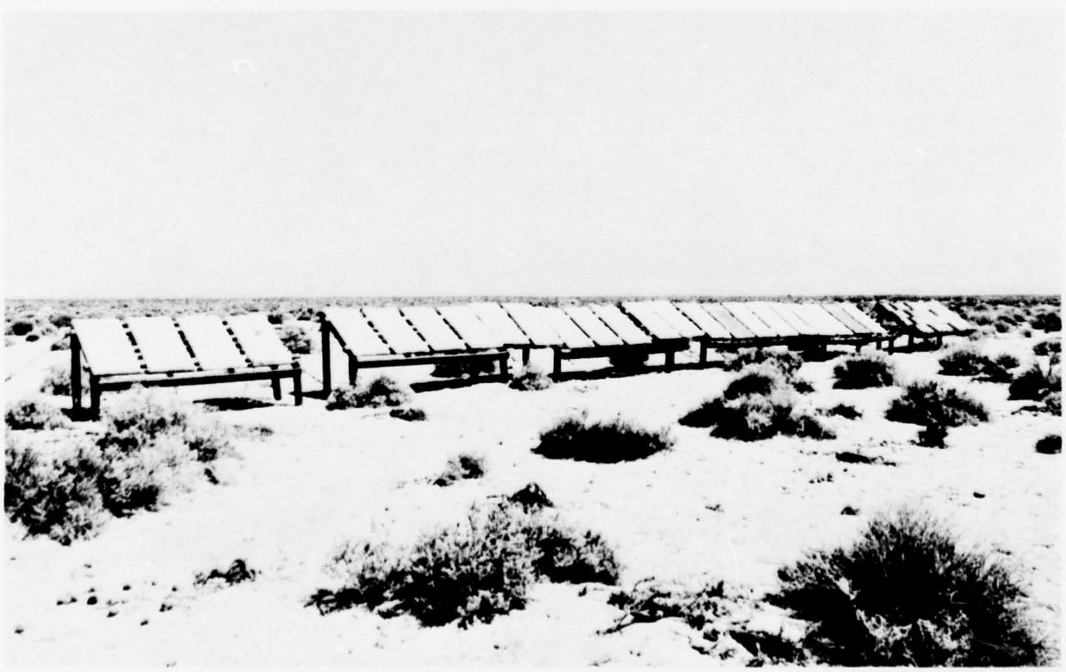


Figure 2. Experimental panels at desert site, NWC, China Lake, California.

(a) Summer.

(b) Winter.

Figure 3. Experimental panels at cold weather site, MCMWTC, Pickel Meadows, California.

E = Excellent — The system is performing without any noticeable deterioration.

VG = Very good — Only very minor deterioration of the system.

G = Good — Although the system shows some deterioration, it is not yet serious.

P = Poor — System deterioration is becoming serious. Remedial action will be required in the near future.

F = Failed — Deterioration of the system has advanced to the point of requiring immediate maintenance.

The overall performance ratings are given in Table 2 and discussed later in the report.

Photomacrographic Studies. During the inspections, photomacrographic studies were conducted on all of the systems at each site. Photomacrographs were taken of five different spots, about 1 inch by 2 inches in size, on each panel. A template is used so that the same five spots are photographed during each inspection, thus providing a progressive record of coating deterioration. Enlarging of these photomacrographs also provides a record of initial deterioration that is not obvious to the naked eye. Results of these studies together with examples of the photomacrographs are presented later in the report.

Foam Degradation Rate Studies. Each time a group of coated PUF experimental roofing panels was placed on exposure at a weathering site, uncoated control panels were also exposed at the same site. They were included to enable determination of foam degradation rates as well as to disclose information on the mechanism of degradation.

The device for determining foam degradation is shown in Figure 4. It consists of a rigid gage reference bar (A), made of aluminum 1 inch thick, which is properly positioned by seating its legs in two positioning pads (B) permanently attached to the supporting 2 x 4 inch cross-piece of each panel. Readings on the specimen are made by inserting a micrometer depth gage into each of 11 holes drilled in the reference bar; in Figure 4, the depth gage is shown in hole 4. Degradation of the foam is determined by noting changes in the distance from the reference bar to the foam surface from reading time to reading time. Before depth gage readings are made, degraded foam is brushed away so that the depth gage is seated on a sound foam surface. The foam degradation rate was determined by dividing the total degradation in inches by the total exposure period in months. Results for an exposure time of 8.3 months are shown in Table 3 for foams having densities of 2 and 2.5 pcf.

Laboratory Investigations

In addition to the field exposures, selected physical properties were determined on coated and uncoated PUF samples and on free films of the coating systems included in the investigation. These properties

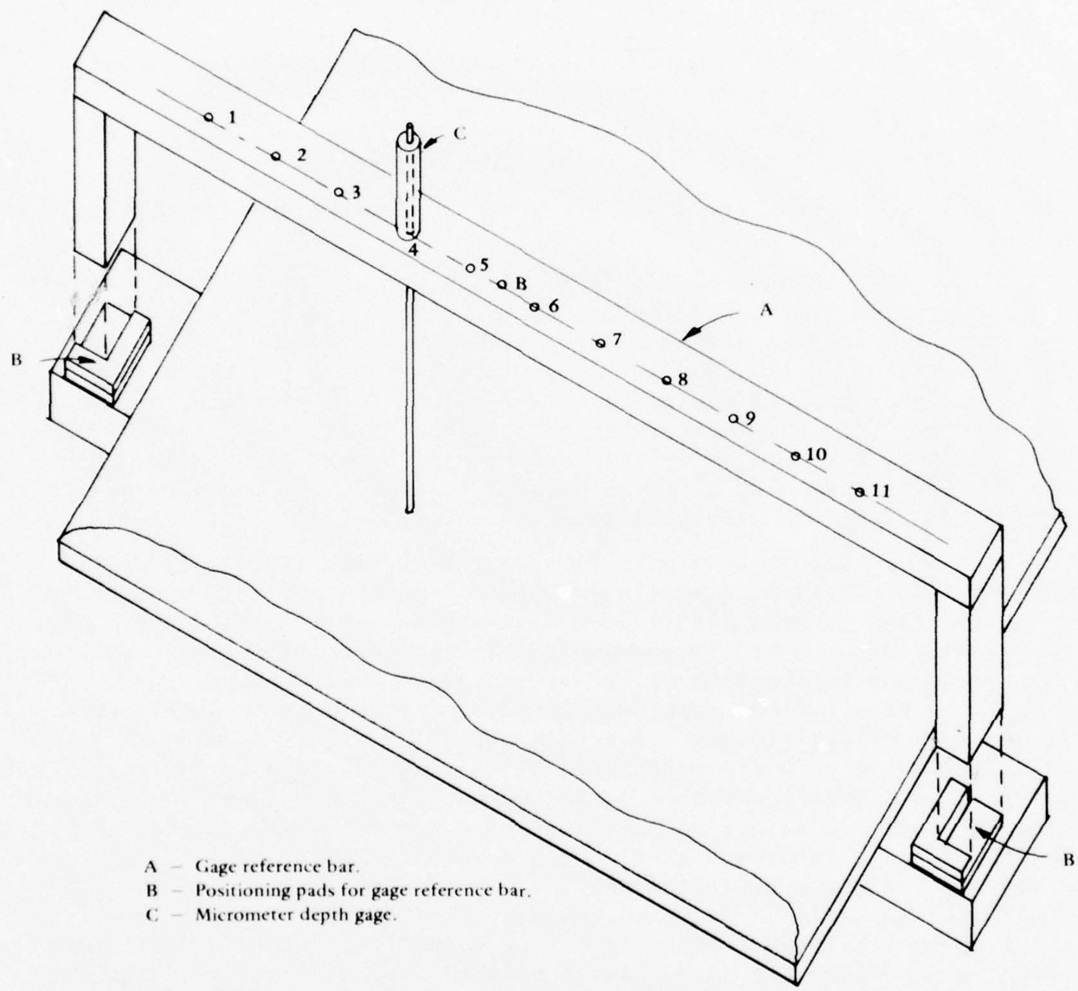


Figure 4. Device for measuring rate of degradation of uncoated urethane foam.

included (1) adhesion, (2) resistance to wind-driven rain, (3) impact resistance, and (4) tensile properties of free films of the coating systems. Properties (1) through (3) were determined on specimens cut from panels exposed at the Port Hueneme site.

Adhesion Properties. The adhesion of the various coatings to the PUF was determined using the CEL-developed adhesion test method on samples cut from the second set of coated PUF panels exposed at the Port Hueneme Site. The adhesion properties were determined before exposure and after 3- and 9-months of exposure. The test consists of "gluing" a cylindrical probe to the coating and then pulling the probe from the coated specimen in a testing machine, causing the coating to fail either in adhesion or cohesion. Except for the silicones, the probes were glued to the coatings with a polyamide-cured epoxy adhesive. A silicone adhesive was used on the silicone coatings. Ten values were obtained for each coating system and the five highest values were averaged. The testing fixture is shown in Figure 5. Results on those that were determined are presented in Table 4.

The adhesion tests were also employed to determine how long the PUF can be allowed to remain uncoated and exposed to sunlight and weathering without affecting the adhesion of the coating to the foam. Twelve 2x4 foot plywood panels containing foam with a density of 2.5 pcf were placed outside at Port Hueneme to weather for periods of 1, 3, 24, 48, and 72 hours, and 9 days before being coated. Six of the panels were coated with the silicone of System 2 and designated as Systems 2-1 through 2-6 while the other 6 were coated with the neoprene-hypalon of System 7 and designated as Systems 7-1 through 7-6. The adhesion of these coated PUF systems, determined after being exposed for two months and for nine months at the Port Hueneme site, are presented in Table 5.

Wind-Driven-Rain Resistance. The procedure described in military specification MIL-C-555 was used for this test. Basically, the procedure consists of providing a curtain of water on the coated face of the PUF specimen. This water-curtained surface was then pressurized at 5 psi to simulate the force of a wind-driven rain. The amount of water absorbed is determined by weighing the specimen before and after exposure. Table 6 shows results of wind-driven rain tests made on specimens cut from the second set of panels (exposed at Port Hueneme) before they were exposed and after exposure periods of 3 and 9 months. Table 7 shows similar data for specimens cut from the panels which had been allowed to weather prior to coating.

Impact Resistance. The impact test device, shown in Figure 6, was similar to that described in Reference 1. The impactor (called TUP in Reference 1) consists of a plastic cylinder with a 1 inch-diameter steel ball at the bottom. Metal shot can be added to the impactor to vary the weight. The impactor was dropped through a plastic pipe with a 1-1/2 inch inside diameter for a distance of 5 feet, at which point the steel ball portion impacted the coated surface of the PUF specimen. Starting with the minimum weight of 160 grams, the impactor weights used were 160, 200, 300, 400, and 500 grams (maximum). Each test was continued

until the impactor caused a break in the coating or until the maximum of 500 grams was reached. At least five impacts were made at each impactor weight. Results of these tests are shown by means of bar graphs in Figure 7.

Tensile Properties of Free Films of the Coating Systems. The procedure for determining the tensile properties of coating systems used in this part of the laboratory investigation was that described in Reference 5. Glass plates, one surface of which was treated with a release agent, were placed alongside the experimental foam panels. The protective coatings included in this investigation were applied to the treated glass surface at the same time they were applied to the foam surfaces. Where the system consisted of two coats, both the base coat and topcoat were applied to the glass plate. The coating systems were allowed to cure on the glass plates and were then stripped off. Prior to testing, the free films were permitted to equilibrate for at least 7 days in a controlled environment of 50% R.H. and $70^{o}F$. They were then cut into strips approximately 2 cm wide with a special cutter and their thickness determined with a micrometer. At least ten specimens were tested to failure and the five highest values for tensile strength and for percent elongation were averaged. Results are listed in Table 8.

RESULTS AND DISCUSSION

Visual Inspections at Field Exposure Sites

The principal objective of this investigation was to determine how long the candidate PUF roofing systems perform satisfactorily when exposed to the weather and which of the candidate systems were superior to the others. In achieving the objective, the PUF systems were exposed to three different climatic conditions, i.e., marine, desert, and cold weather. Experience has shown that if the PUF is properly applied to a suitably prepared substrate, the performance of the system is primarily dependent on the performance of the protective elastomeric coating system. That is, with a high quality foam, if the coating performs well, the PUF roofing system as a whole can generally be expected to perform well. The performance of the coated PUF panels at the three sites was monitored periodically. Results for each of the systems are tabulated in Table 2 and are discussed below.

Visual inspection, rating, and photographing of the experimental PUF roofing systems at the three sites have been done at about 6 month intervals up to a current total of 2 years. Because all systems were not exposed at the same time, all do not have ratings for as long as 2 years.

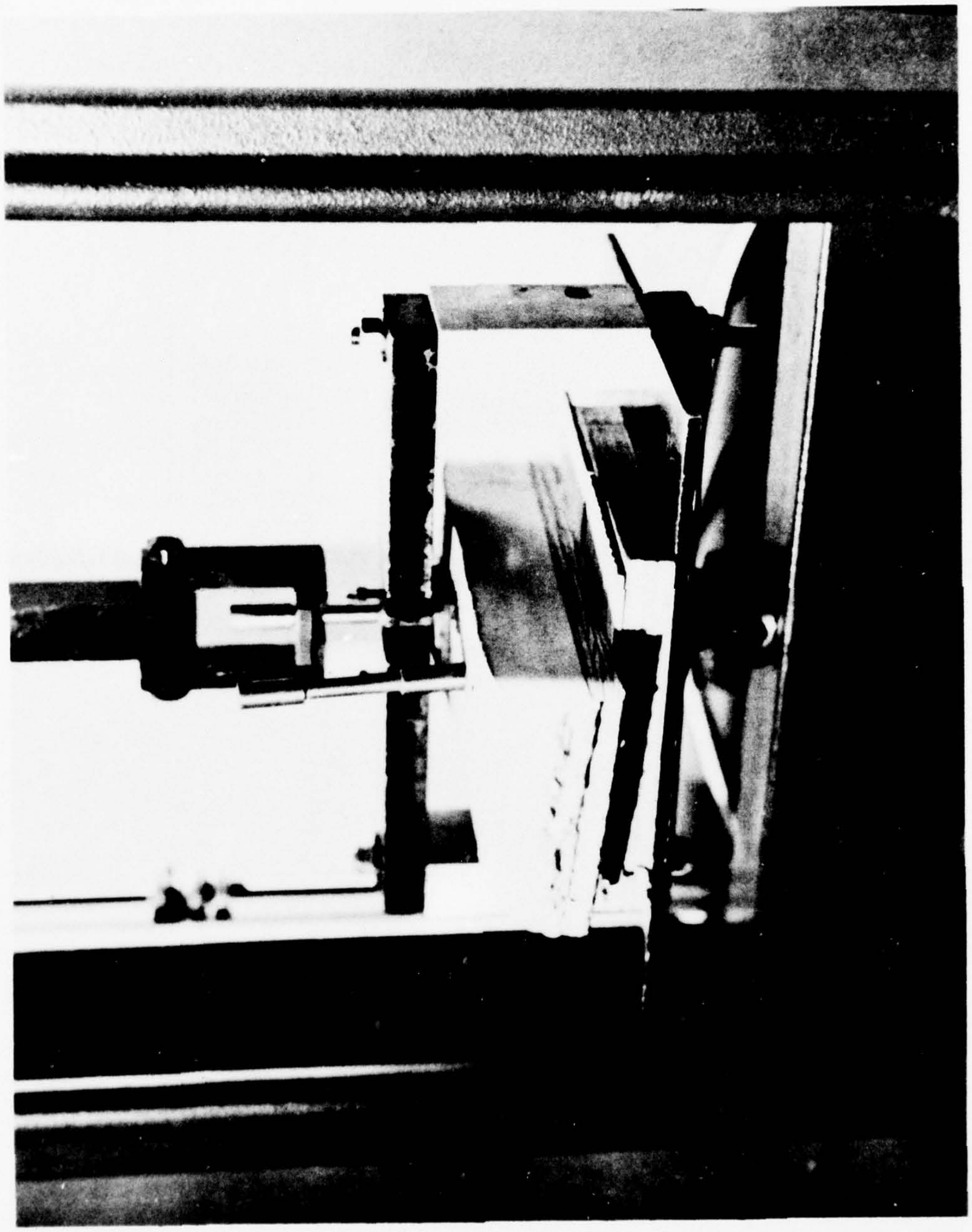


Figure 5. Fixture for determining adhesion properties.

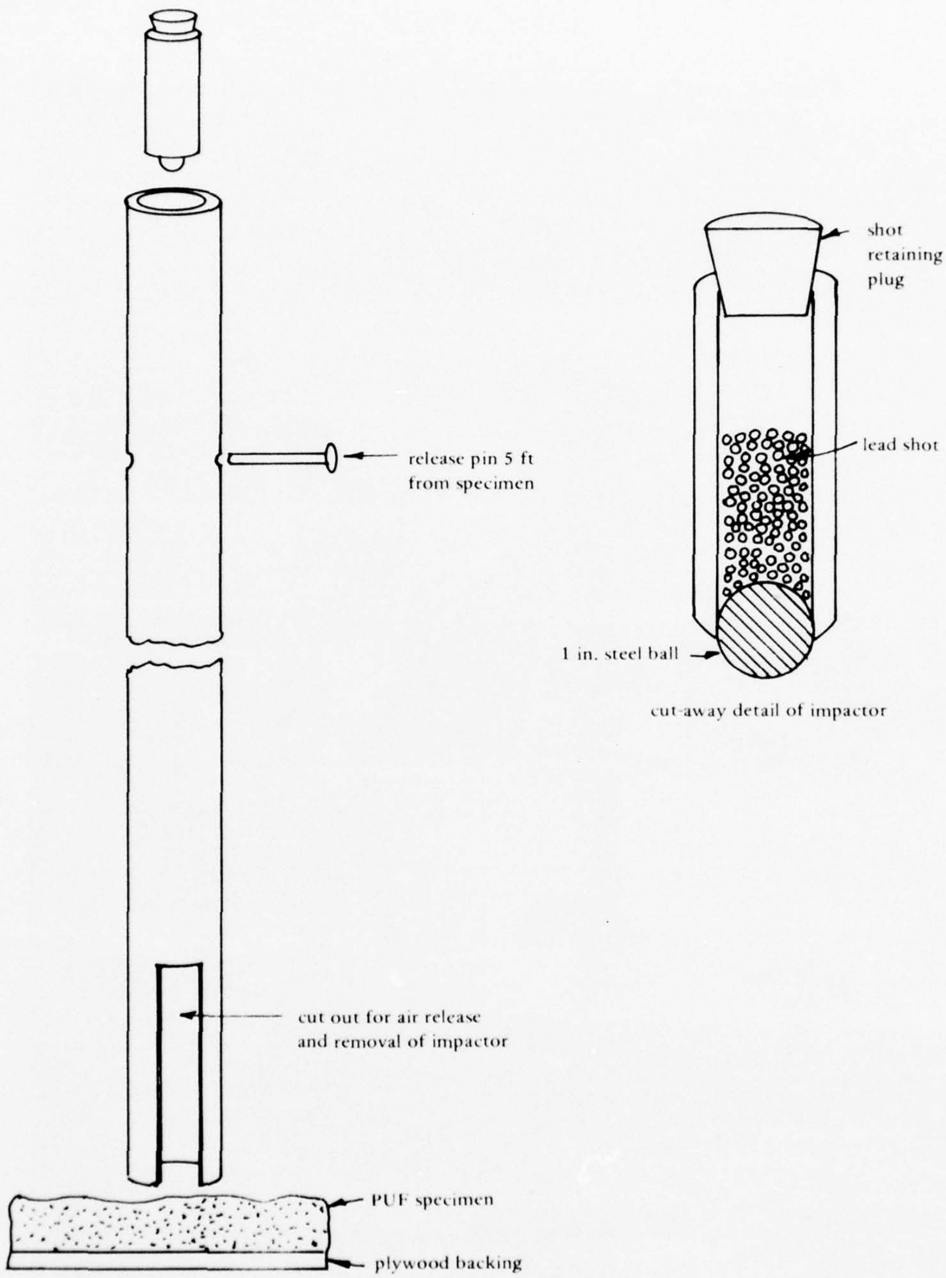
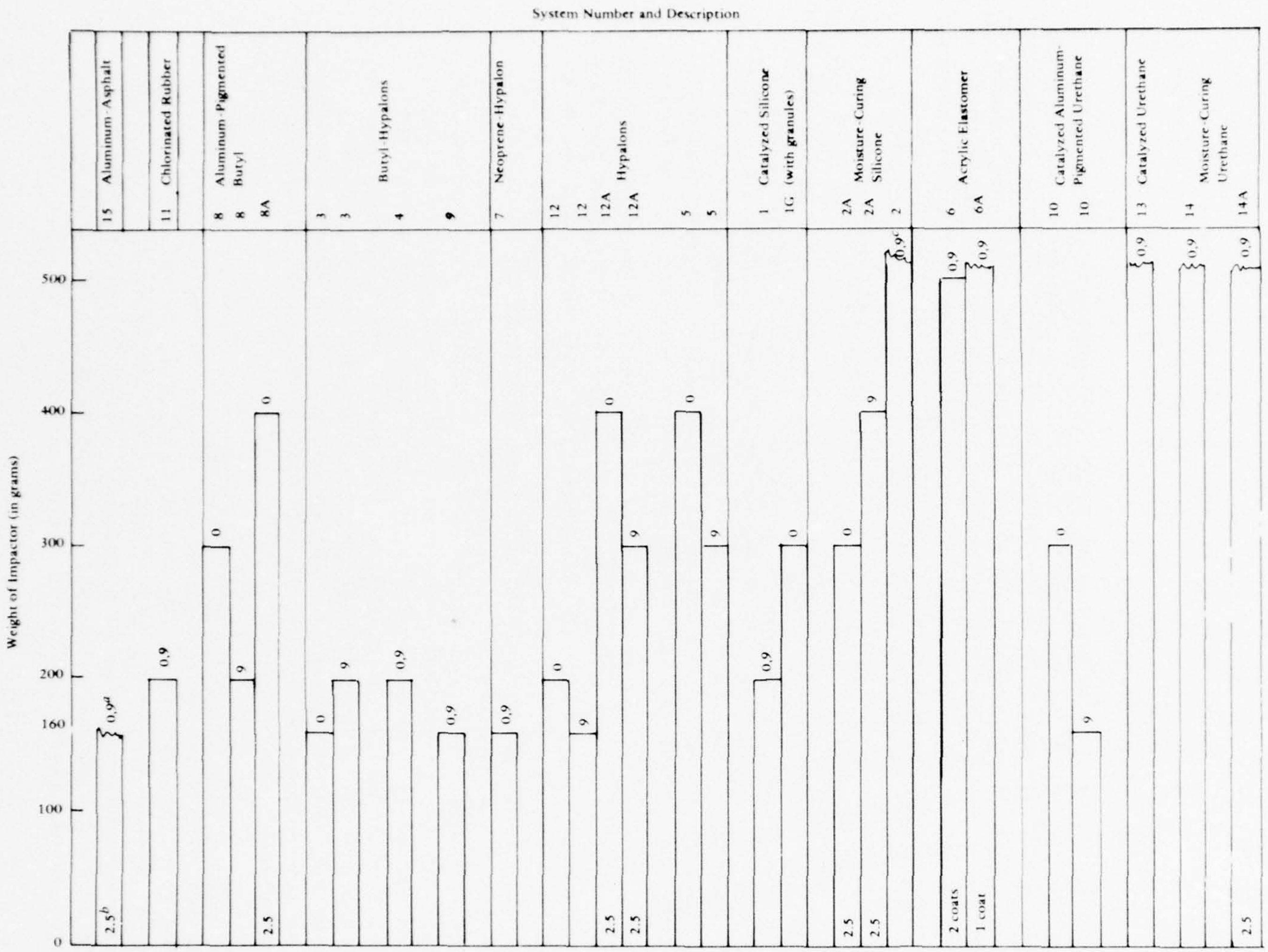


Figure 6. Impact tester and weighted impactor.



[a] Time in months that samples were weathered in atmosphere before testing.

[b] *Density of foam was 2.0 pcf unless noted as 2.5 pcf.*

[c] Irregular line on top of bar indicates failure due to impact either above 500 grams or below 160 grams.

Figure 7. Results of impact tests.

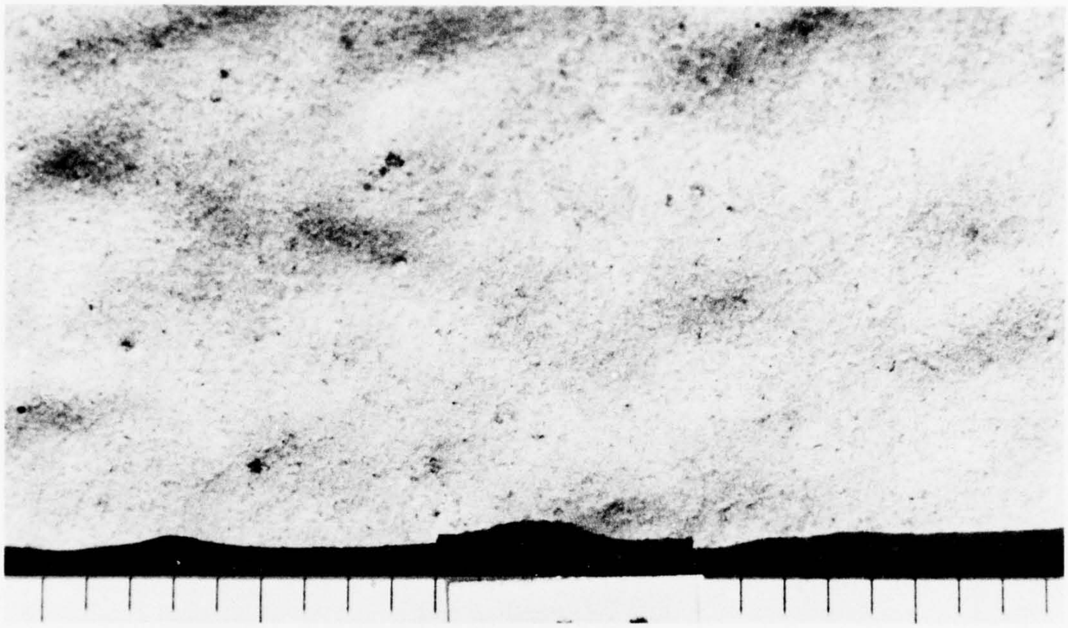
Systems 1 and 1G — Catalyzed Silicone Rubber and Catalyzed Silicone Rubber With Granules. These silicone rubber systems have performed very well at the three sites for periods of 1 to 2 years. System 1 retains dirt and thus has a dirty gray appearance but this has not affected its performance. As shown in Figure 8, dirt-retention is not a problem when using the granules (System 1G). The performance of both of these systems was rated as excellent at all three sites.

Systems 2 and 2A — Moisture-Curing Silicone Rubber. These systems are similar to System 1 except that this silicone cures by reacting with moisture in the air and thus does not require special spraying equipment to apply. After 1 year of exposure at Pickel Meadows, the performance of System 2 is rated as excellent. Figure 9 shows typical checking or cracking of the coating which occurred in depressions on the Port Hueneme and China Lake panels before these panels were exposed; it has not become more severe after two years of exposure. The performance of the systems at these two locations was rated as very good for their respective exposure periods.

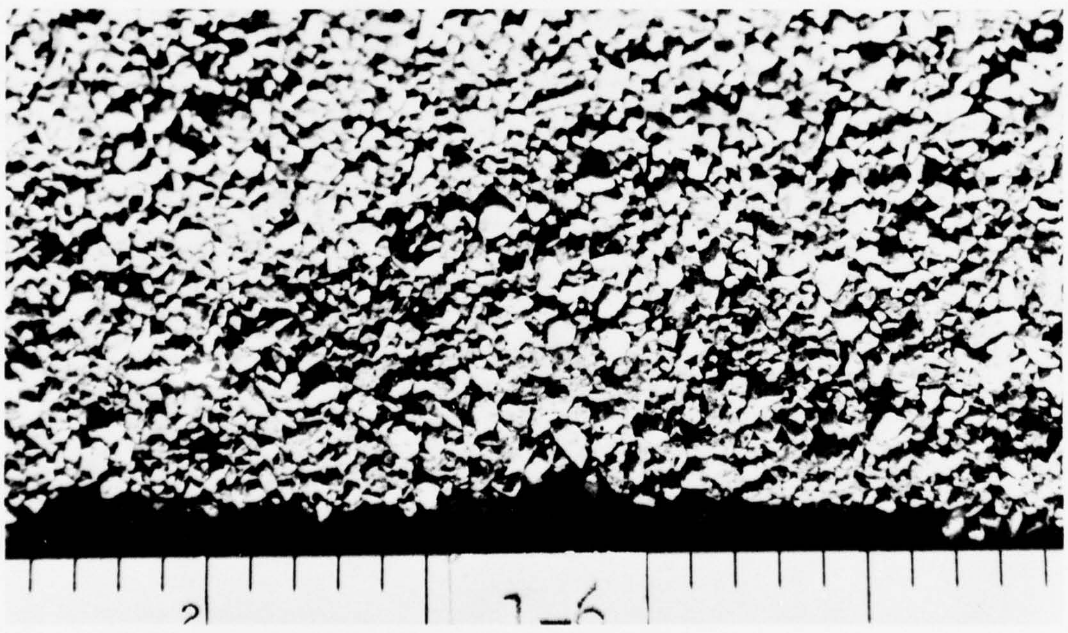
System 2A panels were prepared after the checking or cracking was noted on System 2. Performance of System 2A was rated as excellent after 6 months of exposure at China Lake and Pickel Meadows and 1 year at Port Hueneme. Like the System 1 silicone, the System 2 moisture-curing silicone rubber also retains dirt; the white topcoat attains a dirty gray appearance on exposure which has not affected its performance.

System 3 — Catalyzed Butyl-Hypalon. The dense solvent pinholes in the topcoat of this system were the focal points for incipient deterioration. The topcoat tended to lose adhesion and curl back from the base coat in the general area of the pinhole. The photomacrographs in Figure 10 show this quite dramatically for the panel exposed at China Lake for various periods of weathering. The topcoat of hypalon gradually peeled, exposing the butyl base coat which then deterioriated and exposed the foam directly to the weather. The most rapid deterioriation of the system occurred at China Lake where it had failed by the end of the first year of exposure. Performance of System 3 was almost as poor at the Pickel Meadows site, where the system was also nearing failure following one year of exposure. The exposure at Port Hueneme was not quite as severe and the system was rated as good to poor after 2 years of weathering.

Systems 4 and 4A — Catalyzed Butyl-Hypalon. Very dense shallow solvent pinholes which were evident when the panels were exposed have not lead to deterioration of the coating system to date. The coating systems of System 4 were damaged slightly in transit to the test sites; thus System 4A was prepared to supplement System 4. After exposure periods of from 6 months to 2 years, the performance of these systems was rated as excellent.



(a) Dirt retention on catalyzed silicone rubber (System 1) after 18 months of exposure.



(b) Practically no dirt retention visible on catalyzed silicone rubber with granules (System 1G) after 18 months of exposure.

Figure 8. Effects of roofing granules on dirt retention.

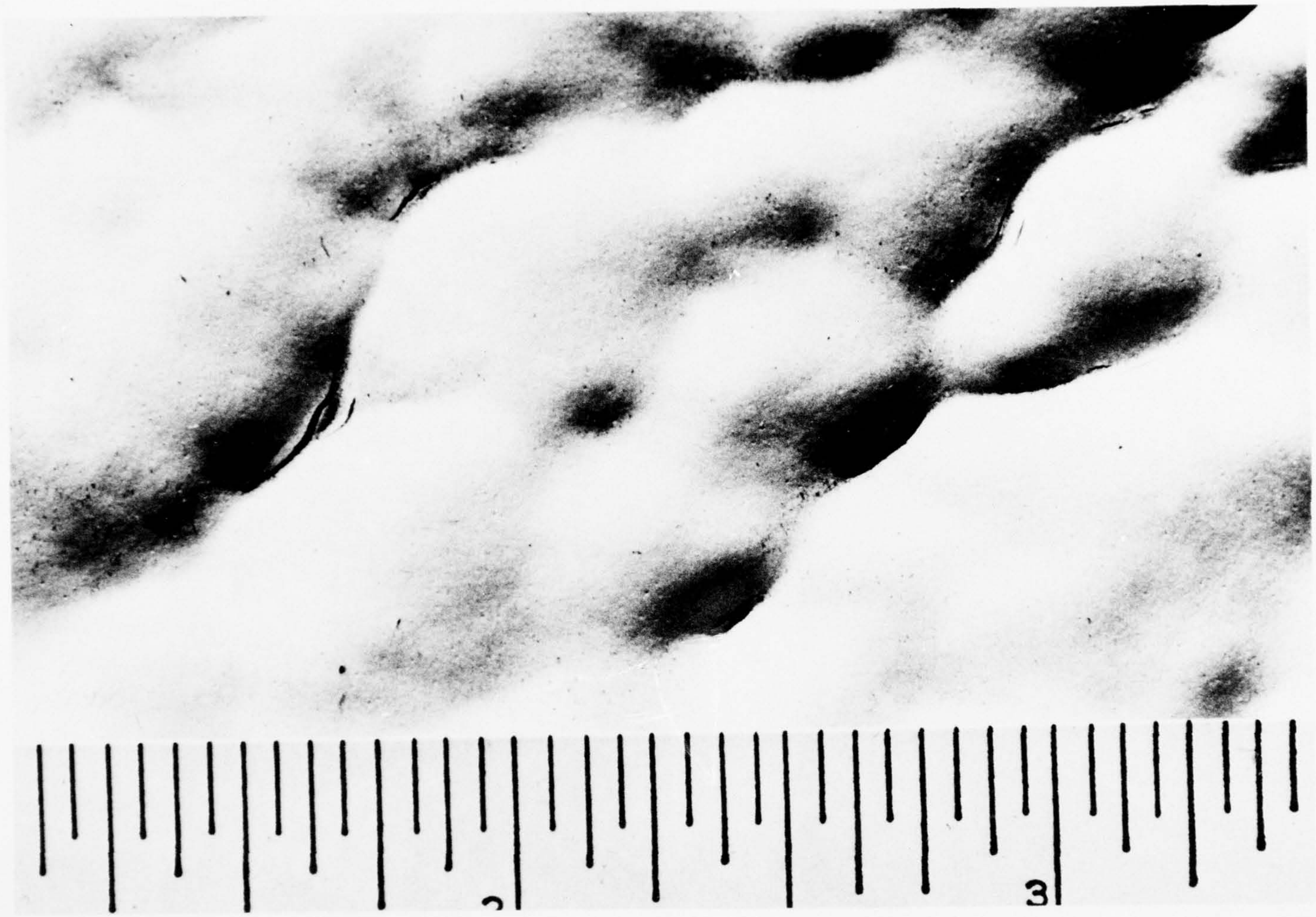
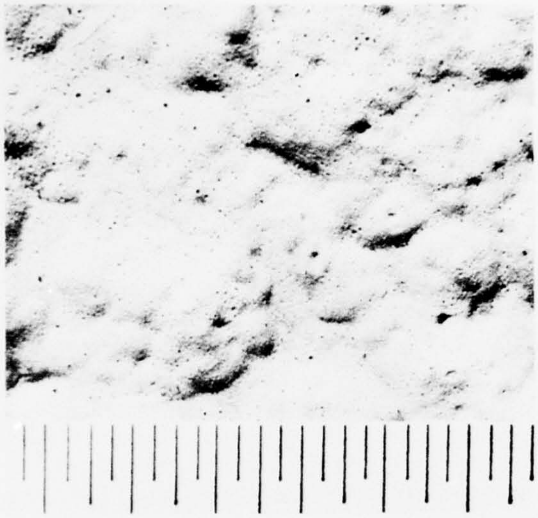
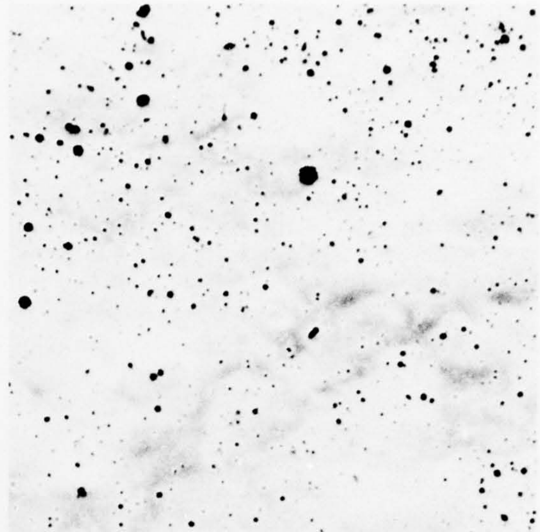


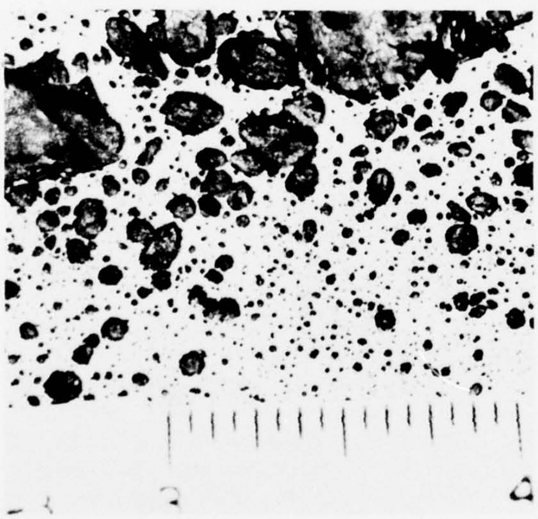
Figure 9. Checking or cracking of moisture-curing silicone rubber coating (System 2). (China Lake; before exposure.)



(a) Before exposure.



(b) After 6 months of exposure.



(c) After 1 year of exposure.

(d) Overall.

Figure 10. Progressive degradation of catalyzed butyl-hypalon (System 3) after various periods of weathering at China Lake.

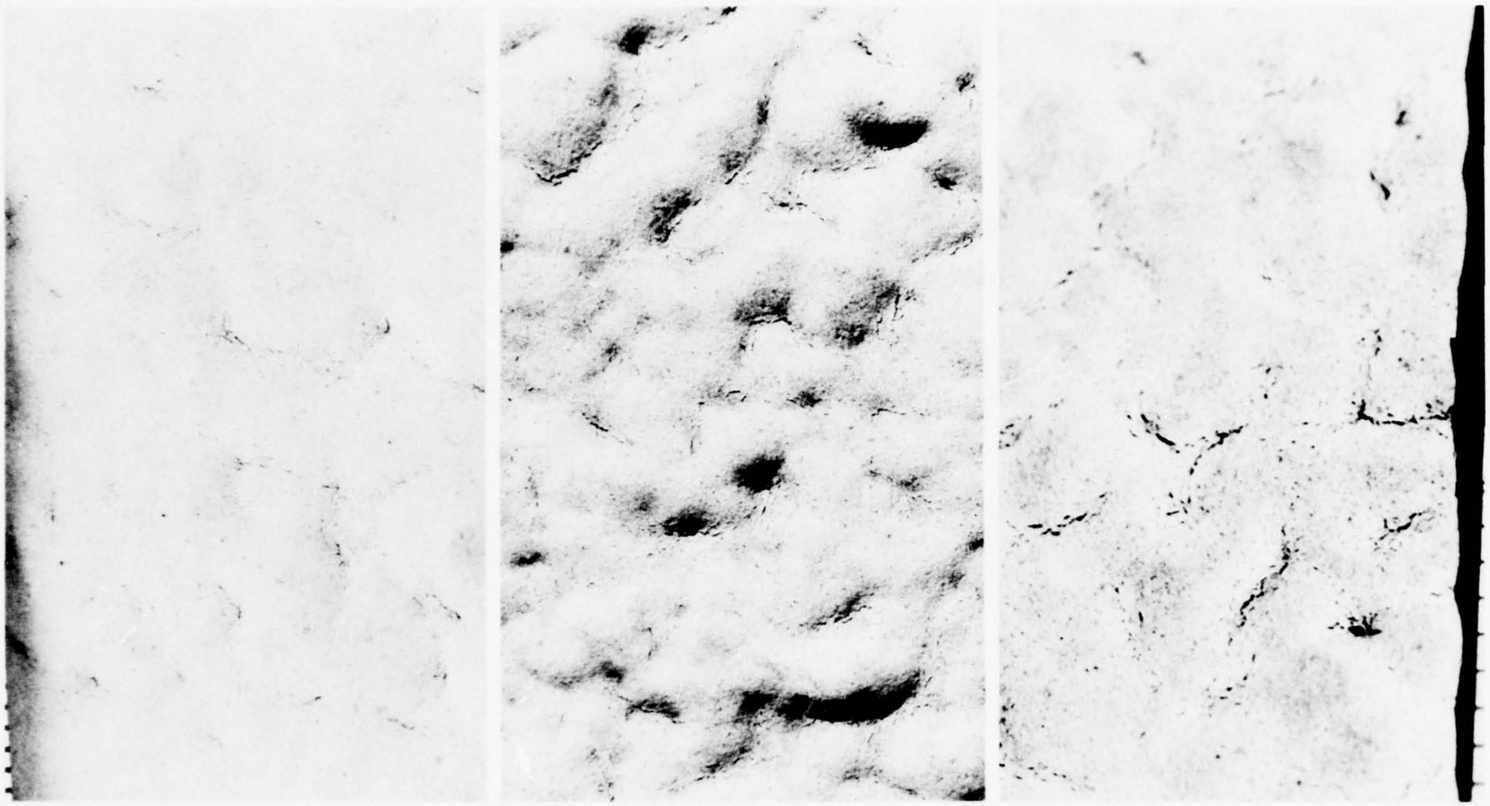
System 5 — Hypalon Mastic. This system exhibited dense shallow pinhead-sized depressions in the coating. However, the system has performed satisfactorily and after exposure periods of 1 to 2 years, this PUF roofing material was rated as excellent.

Systems 6 and 6A — Elastomeric Acrylic Emulsion. System 6 was a two-coat application of this coating, while System 6A was a single-coat application. The single-coat application on the Port Hueneme panel resulted in very light checking in depressions shortly after it was placed on exposure. As shown in Figure 11, this checking has not increased during exposure. Similar checking was not found on panels of System 6A exposed at the other sites. Although the performance of the System 6A panel exposed at Port Hueneme was rated as very good after two years of exposure, all other panels of both Systems 6 and 6A were rated as excellent after exposures of 1 to 2 years. As with the silicones, dirt and soil are not easily washed from the surface of this coating; thus, it has a dirty gray appearance but this does not appear to affect its performance.

System 7 — Neoprene-Hypalon. This system also had many shallow-to-deep solvent pinholes over the three panels. However, to date, these pinholes have not contributed to deterioration of the system. After periods of weathering from 1 to 2 years, the performance of this system was rated as excellent.

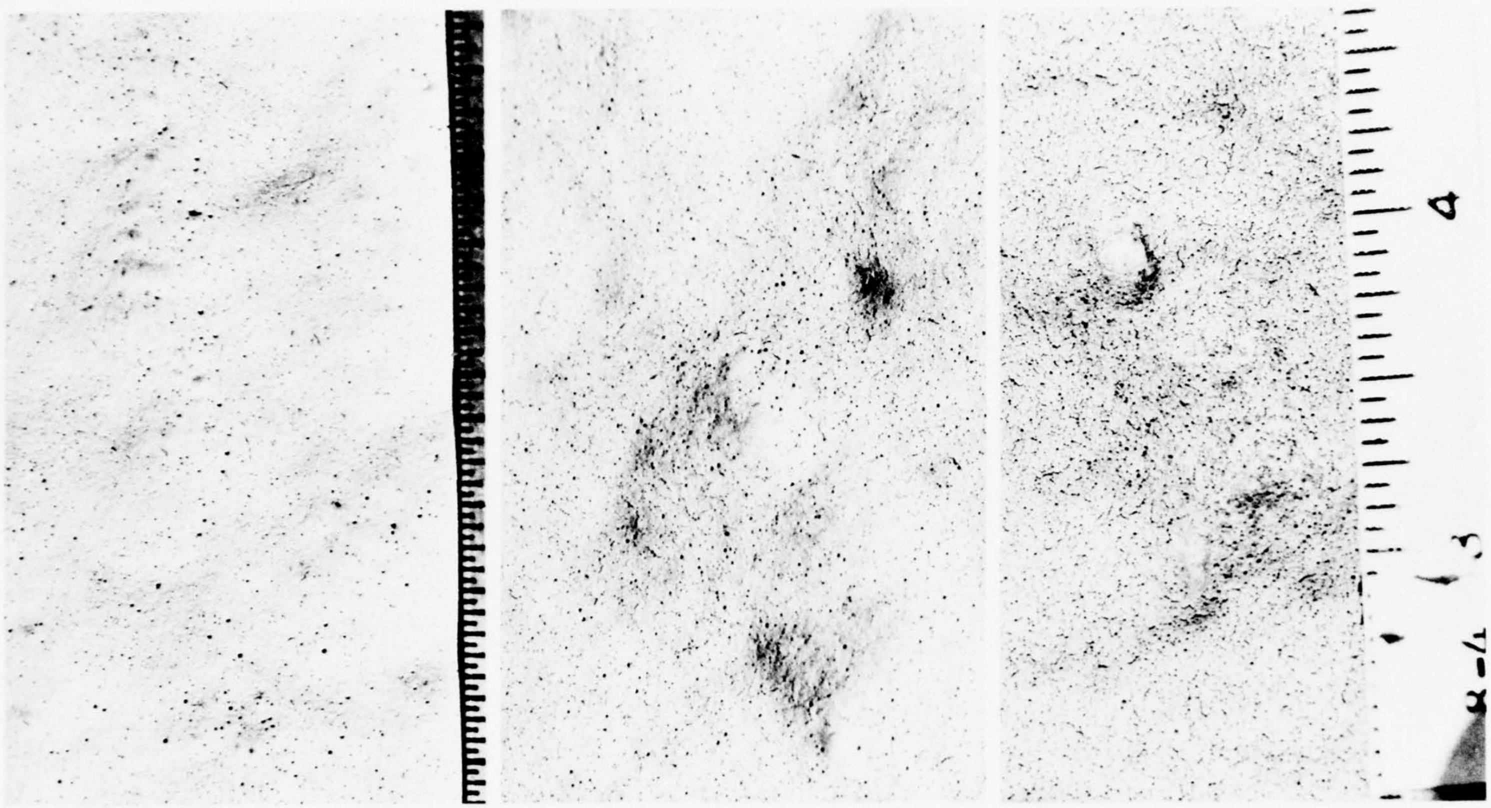
Systems 8 and 8A — Aluminum-Pigmented Catalyzed Butyl. The coating of System 8 was slightly damaged during transit to the test sites, and System 8A was prepared to supplement System 8. Very dense shallow solvent pinholes were characteristic of the aluminum-pigmented butyl of System 8. There were, however, only scattered pinholes in System 8A, presumably because of better application procedures. Pinholes in System 8 became more evident after weathering, particularly at Port Hueneme and Pickel Meadows, as indicated in Figure 12. As with System 3, the solvent pinholes appear to be the focal point for coating deterioration. However, this system is still performing relatively well after 1 to 2 years of exposure at the three sites. Its performance was rated as good at Pickel Meadows (1 year), very good at Port Hueneme (2 years), and excellent at China Lake (1 year). At report time, System 8A had been exposed for only 6 months at Pickel Meadows and China Lake and for only 1 year at Port Hueneme; performance of all three panels was rated as excellent.

System 9 — Catalyzed Butyl-Hypalon. Although this system also had very dense shallow-to-deep pinholes that appear characteristic of the butyl-hypalon coating systems, there appears to be little or no coating deterioration to date. The performance of the system was rated as excellent after 1 year at China Lake and Pickel Meadows and 2 years at Port Hueneme.



(a) Before exposure. (b) After 6 months of exposure. (c) After 2 years of exposure.

Figure 11. Light checking in depressed areas of System 6A, 1 coat acrylic elastomer after various periods of weathering at Port Hueneme.



(a) Before exposure. (b) After 6 months of exposure. (c) After 1 year of exposure.

Figure 12. Progressive development of pinholes with weathering of aluminum-pigmented catalyzed butyl (System 8) at Pickel Meadows.

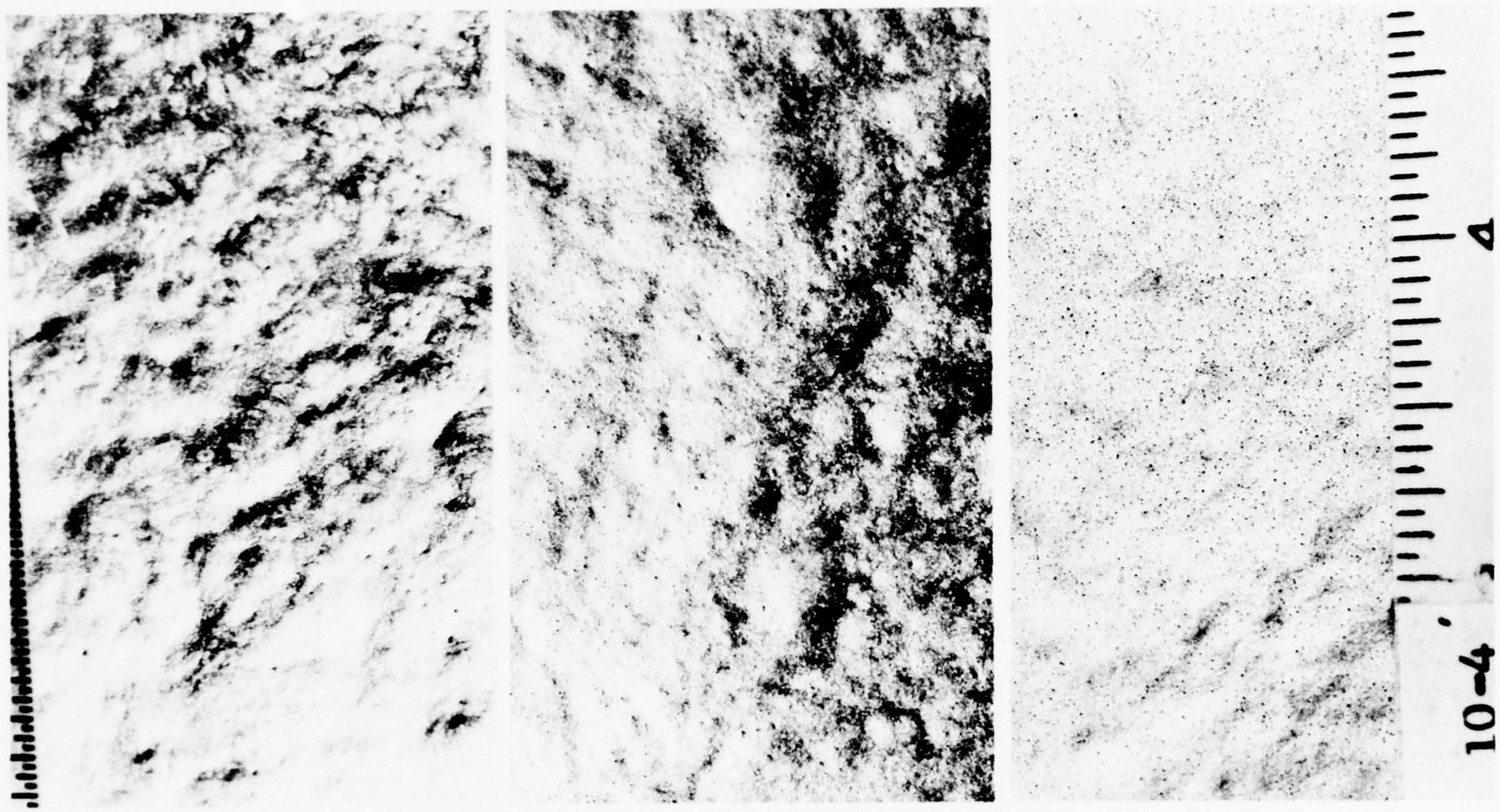
System 10 — Aluminum-Pigmented Catalyzed Urethane. As mentioned earlier, this system tended to flow into low areas on the panel when applied and to attain a much greater thickness at these points. As a result, the coating was somewhat thinner on the higher areas of foam. To date this has not affected its performance, but incipient deterioration may be occurring as indicated in Figure 13 by the increasing number of black specks becoming evident with additional exposure. Its performance was rated as excellent after 2 years at Port Hueneme and excellent after 1 year at the other two sites.

System 11 — Chlorinated Rubber. Although easily stained, this system is performing very well. After exposure to the weather for periods of from 1 year at Pickel Meadows and China Lake to 2 years at Port Hueneme, the performance of this system was rated as excellent.

Systems 12 and 12A — Hypalon Mastic. System 12 sprayed very unevenly and exhibited more shallow-to-deep pinholes than were encountered in any of the other systems investigated. System 12A was then applied under the direction of the manufacturer's representative and went on quite evenly with very few pinholes. Contrasting surface textures can be seen in Figure 14. Both systems were exposed to determine their relative performance. To date both have been performing very well and after exposure periods ranging from 6 months to 2 years, their performance is rated as excellent at all test sites.

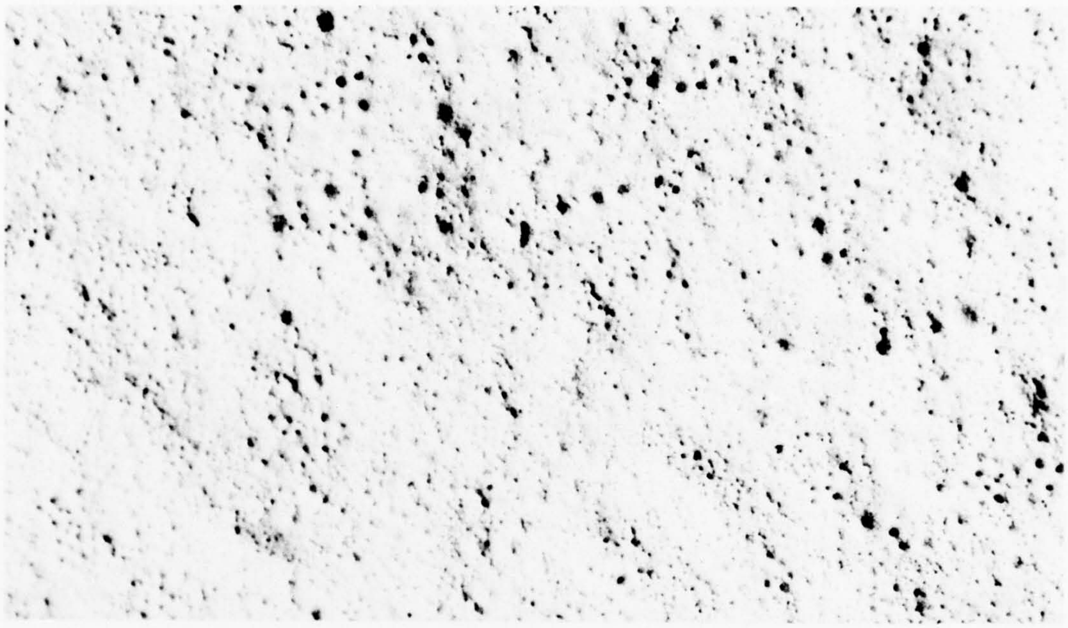
System 13 — Catalyzed Urethane Elastomer. This urethane elastomer has a combination of excellent appearance and performance that has been outstanding to date. It has a glossy white appearance and does not retain dirt, thus maintaining its excellent reflective surface, as shown in Figure 15. After 1 year of exposure at China Lake and Pickel Meadows and 1.5 years at Port Hueneme, the performance of this system was rated as excellent.

Systems 14 and 14A — Moisture-Curing Urethane Elastomer. Great difficulty was encountered with the application of System 14. As a result, System 14A was applied under the direction of the manufacturer's representative. As with Systems 12 and 12A, System 14 had dense solvent pinholes up to 1/16-inch in diameter all over the panel, while System 14A had very few pinholes. Although these pinholes contributed to deterioriation, they were not the only cause. The coating tends to chalk very heavily and shows severe checking and flaking, all of which are attributed to regression of the urethane elastomer and all of which contribute to progressive deterioration such as shown in Figure 16. After 1 to 1-1/2 years exposure, the performance of this system is rated as poor to failed. System 14A however, although chalking heavily, is performing better, and after 6 months to 1 year of exposure, its performance is rated as excellent at all three sites.

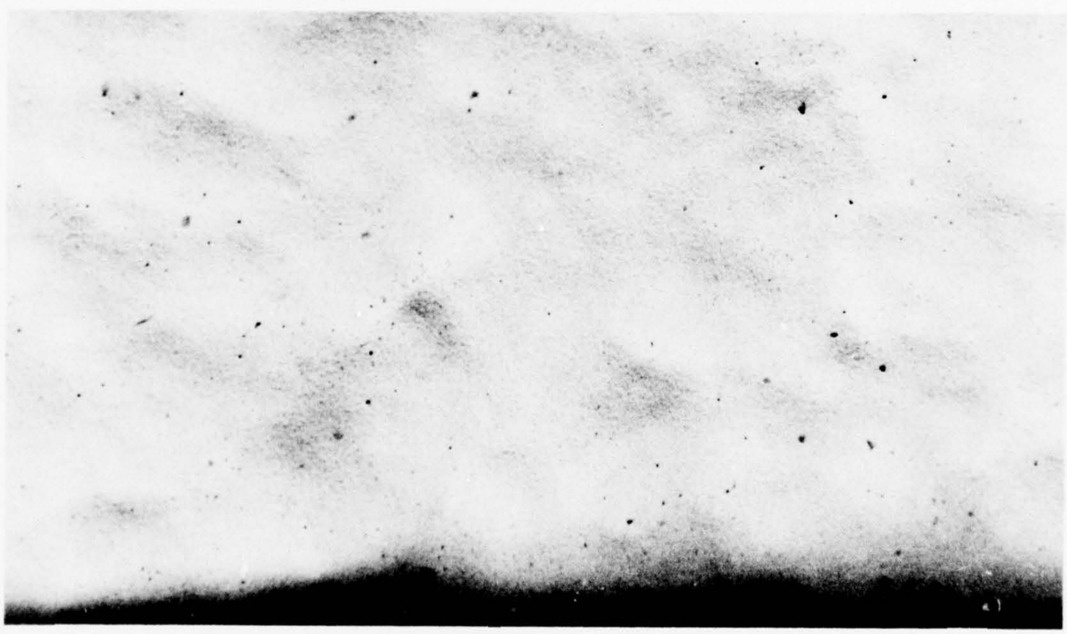


(a) Before exposure. (b) After 6 months of exposure. (c) After 1 year of exposure.

Figure 13. Progressive development of black specks in aluminum pigmented catalyzed urethane (System 10) at Pickel Meadows.



(a) System 12.



(b) System 12A.

Figure 14. Differences in surface texture between Systems 12 and 12A, both hypalon mastic.

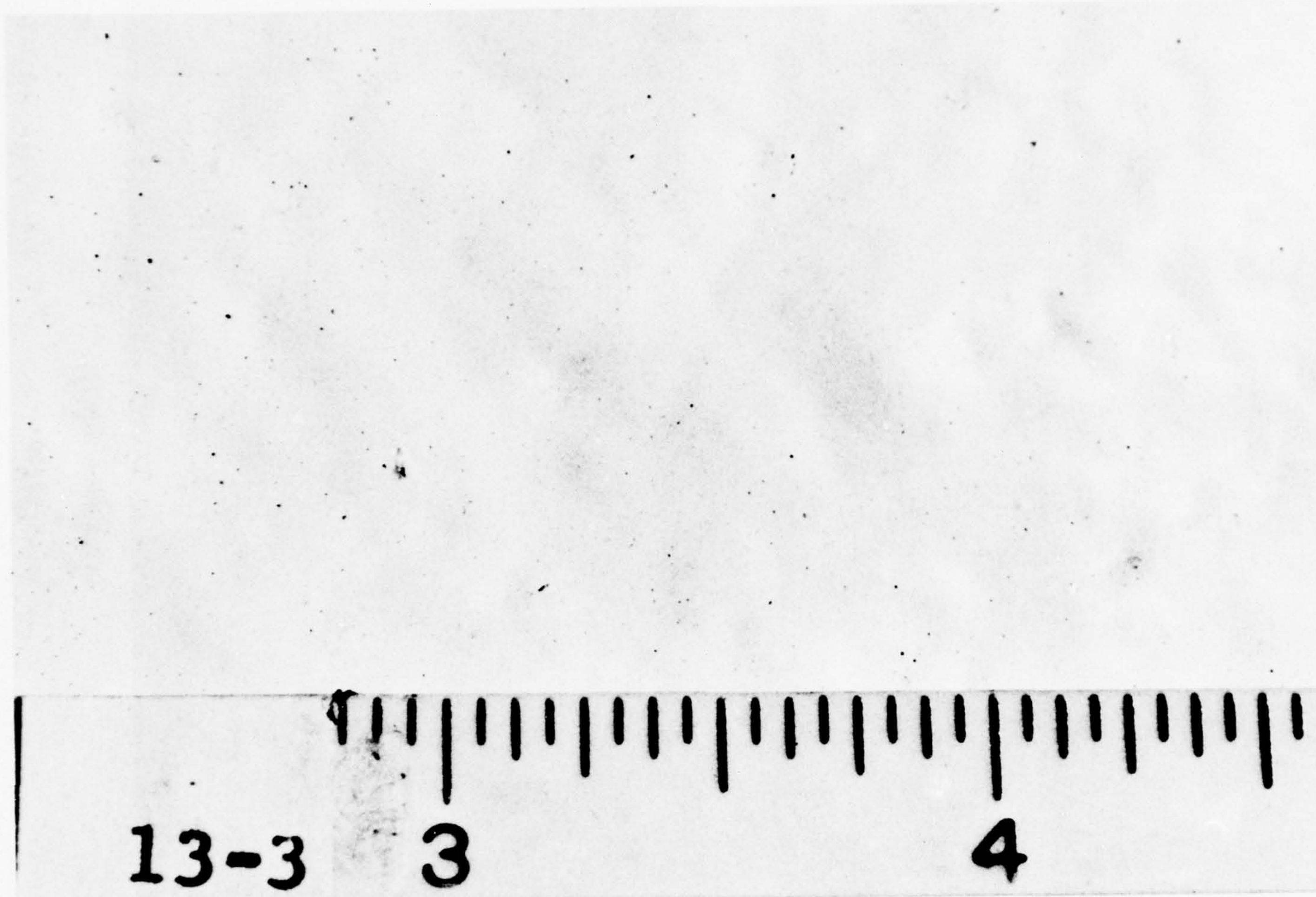
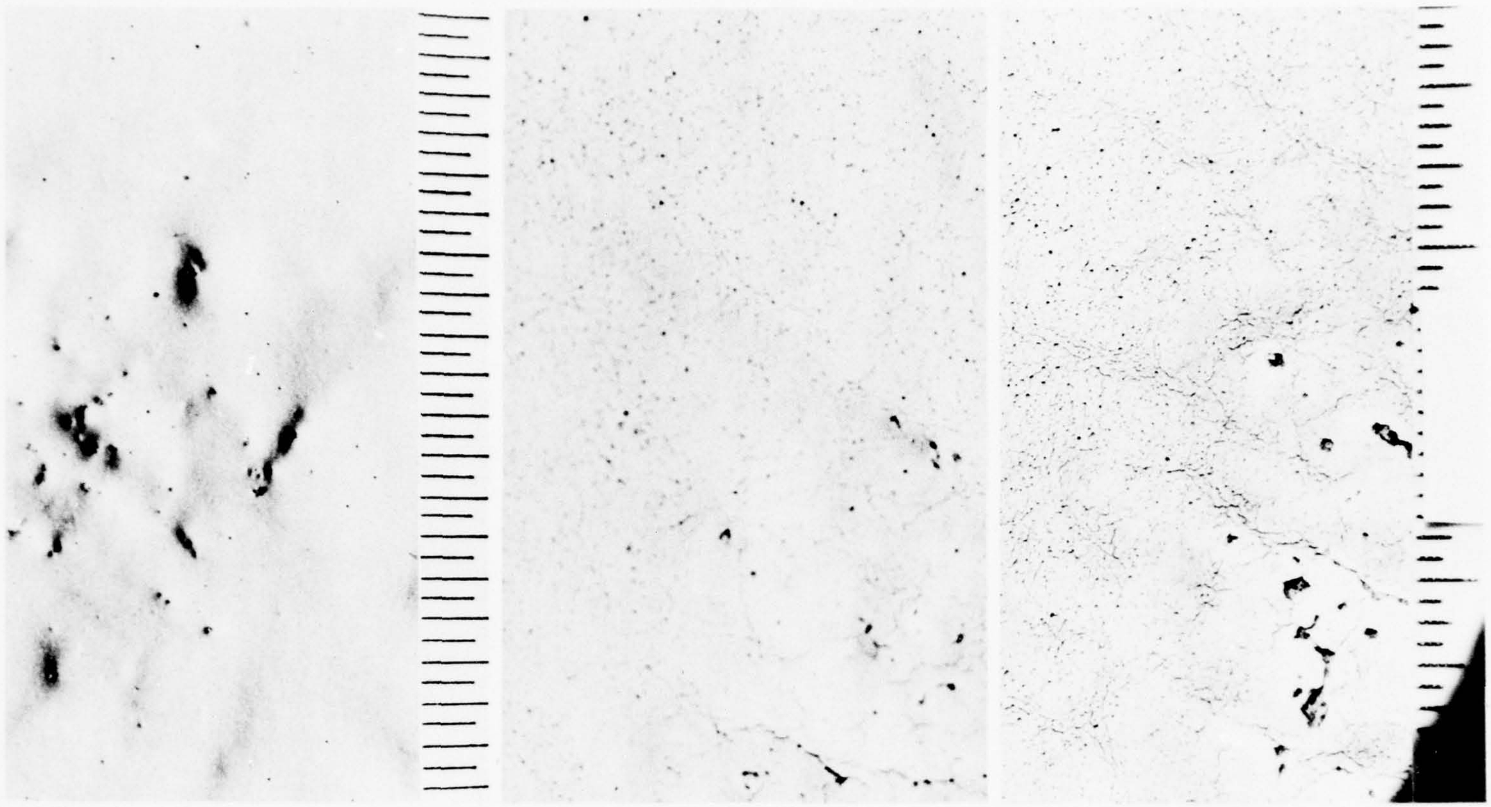


Figure 15. Excellent clean and glossy surface of catalyzed urethane (System 13) after 1 year at China Lake.



(a) Before exposure. (b) After 6 months of exposure. (c) After 1 year of exposure.

Figure 16. Progressive deterioration of moisture-curing urethane (System 14) after various periods of exposure at Pickel Meadows.

<u>System 15 — Fibrated Aluminum-Asphalt</u>. Asphalt and aluminum-asphalt coatings have been widely used over foam in spite of poor performances in the field. System 15, a high quality fibrated-aluminum asphalt, was included as a control. After only 6 months of exposure at the China Lake and Pickel Meadows sites, light deterioration in the form of alligatoring was noted, as shown in Figure 17. In addition, this system was the only coating investigated that was damaged by hail at the Pickel Meadows site; hail damage can be seen in Figure 18. However, neither of these forms of deterioration was severe and this system was rated as very good at both China Lake and Pickel Meadows after 6 months of exposure. System 15 was performing better at Port Hueneme and was rated as excellent after 12 months in a marine atmosphere.

Foam Degradation Rate

Since the foam degradation rates on uncoated panels were determined for only 8.3 months, results shown in Table 3 cannot be considered as completely definitive. However, it seems apparent at this point that foam with a density of 2.5 pcf degrades in thickness more slowly than the less dense 2 pcf foam. Additional exposure and measurements will be required to verify these short-term results.

Adhesion Properties

As noted earlier, a second set of panels of the 15 systems was exposed at Port Hueneme for determining several properties including the adhesion characteristics. These panels were arranged so that they could be periodically removed from the exposure racks, samples cut for the selected property tests, and the remaining part of the specimens returned to the rack for additional exposure. The adhesion properties of the coated PUF samples were determined after 3 and 9 months of exposure and results are given in Table 4.

In addition to the adhesion properties of the coating-foam systems, Table 4 also describes the mode of failure, i.e., whether the coating lost adhesion to the foam or to itself, or whether failure occurred cohesively within the coating or foam. As might be expected, a number of the systems showed more than one mode of failure. However, failure in the majority of those tested occurred cohesively within the foam (failure mode 6). This would be expected with coating systems having good adhesion between coating and foam. Only a few of the failures resulted from loss of adhesion of the coating to the foam.

The butyl-hypalons (Systems 3, 4, and 9), hypalon mastic (System 5), butyl (System 8), and aluminum asphalt (System 15) exhibited a tendency to fail adhesively or cohesively within the coating system. This occurred to a lesser extent with one of the acrylic elastomers (System 6), and two of the urethanes (Systems 13 and 14). The cohesive failure within System 14 (a moisture-curing urethane) after 9 months of exposure, occurred primarily within the severely deteriorated top surface

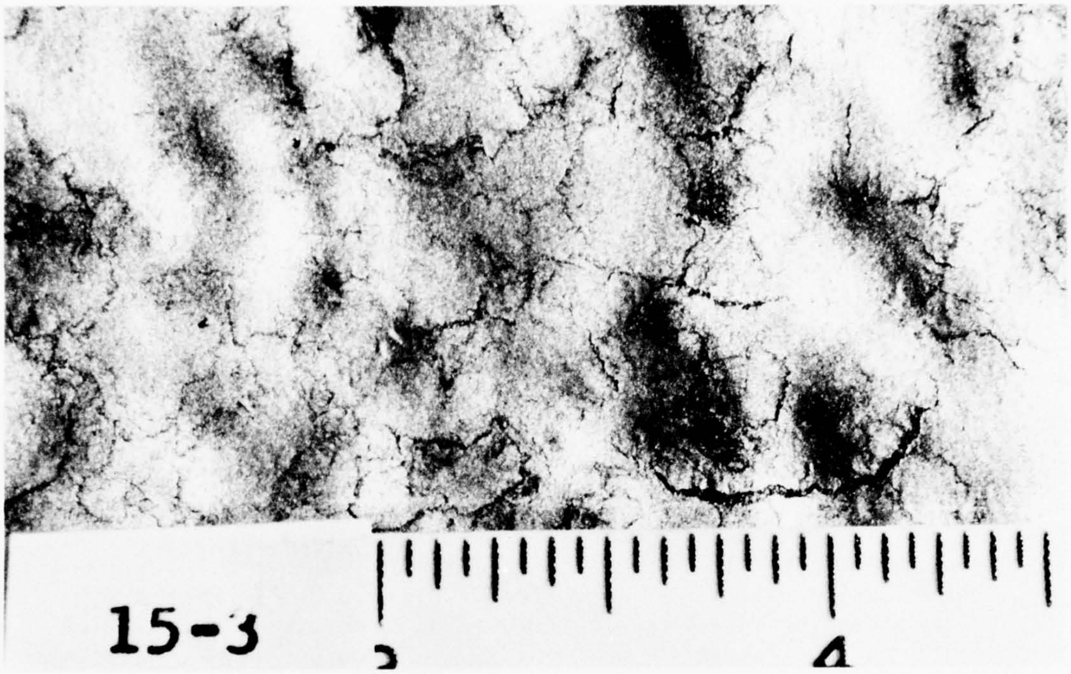


Figure 17. Alligatoring of aluminum-asphalt (System 15) after 6 months at China Lake.

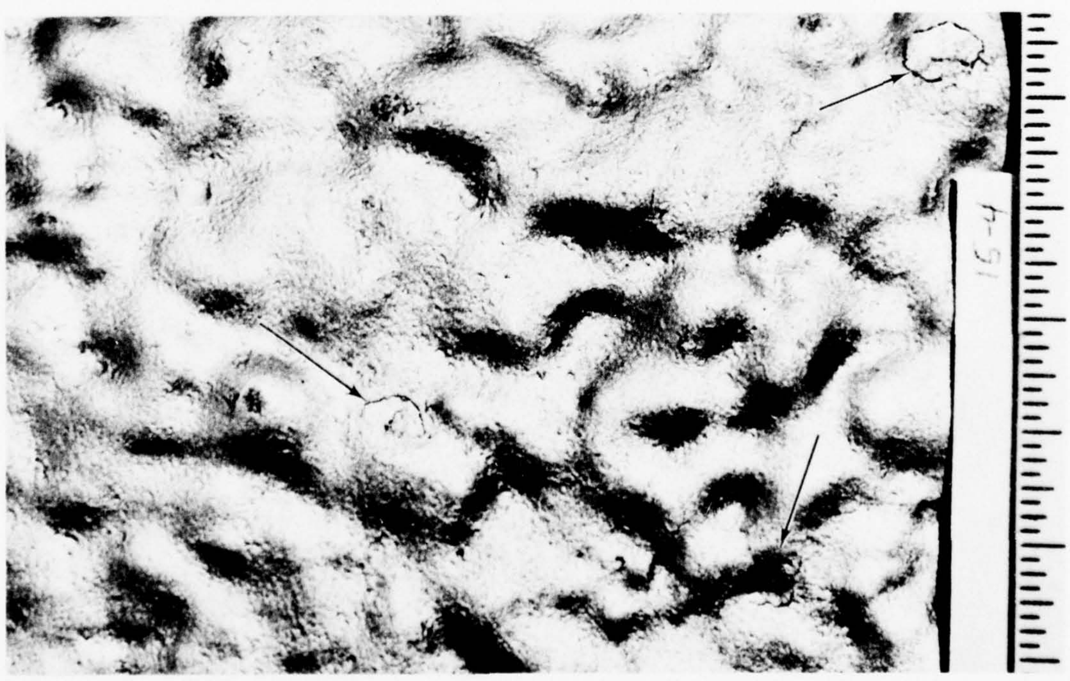


Figure 18. Hail damage in aluminum-asphalt (System 15) after 6 months at Pickel Meadows.

of the coating, while with the butyls or butyl-hypalons and the aluminum-asphalt, the cohesive strength of the coating was merely less than its adhesive strength.

The adhesion properties showed considerable variation even within a given generic type. The silicones as a class exhibited the lowest adhesion strengths, around 10 kg/cm^2, while the hypalons, neoprene-hypalon, and urethanes generally had adhesion strengths of 18 to 22 kg/cm^2. The actual values once the foam has failed cohesively (about 10-12 kg/cm^2 for the 2 pcf foam and 16-18 kg/cm^2 for 2.5 pcf foam) appear to be, at least in part, dependent on the tensile properties of the coating.

With two exceptions, adhesion properties did not generally show large changes with increasing exposure time. Both the moisture-curing urethane (System 14) and the aluminum-asphalt (System 15) showed adhesion properties that were only 50 to 60% of their original values after they had weathered for up to 9 months in a marine atmosphere at Port Hueneme. Except for these two systems, it appears that continued weathering will be required before many of these systems have sufficient deterioriation to reduce their adhesion properties significantly.

The adhesion properties were also determined on the coated PUF panels in which the foam was permitted to age for varying periods of time prior to application of the coatings. These properties were determined after the coated PUF panels had weathered at the Port Hueneme site for 2 and 9 months. Results are given in Table 5.

Unlike the same moisture-curing silicone system listed in Table 4 (System 2), System 2-1 through 2-6 showed failure mostly as loss of adhesion of the coating to the foam (failure mode 3). As a result, the stress values were lower (8 kg/cm^2) than when failure occurred cohesively within the foam as in Systems 2 and 2A (10-11 kg/cm^2). While this is partly a result of exposure of the foam to sunlight before coating, this exposure is not the only factor. This is the case because in this series, those panels exposed only 1 hour and 3 hours before coating also showed adhesion values of approximately 8 kg/cm^2 while similarly exposed panels of Systems 2 and 2A showed adhesion values of 10-11 kg/cm^2. A study of the data for Systems 2-1 through 2-6 in Table 5 suggests that after 9-months rack exposure there is a decrease in the adhesion of the silicone coating system to the foam between the 48 and 72 hour foam-age-before-coating periods, that is between Systems 2-4 and 2-5. However, after 2-months rack exposure, there are subtle reductions in the adhesion starting with System 2-3 (between 3 hours and 24 hours foam-age-before-coating periods).

The neoprene-hypalon, Systems 7-1 through 7-6, showed a more obvious reduction in adhesion strengths between the 72 hour and 7 day foam-age-before-coating period (i.e., between Systems 7-5 and 7-6). The initial adhesion strengths were essentially the same as for the same coating (System 7) given in Table 4, and most of the failures occurred cohesively in the foam.

There appears to be very little difference in the adhesive/cohesive character of Systems 2-1 through 2-6 after weathering 9 months compared to the initial values obtained after 2 months. Systems 7-1 through 7-6 show a greater reduction in these properties after 9 months compared to the 2 month exposures. However, because exposures have been short term, longer weathering time is necessary to determine the significance of these data.

Wind-Driven Rain Resistance

As indicated in Table 6, before exposure, only three systems absorbed about the same amount of water as the uncoated control, i.e., around 2 grams. These were an acrylic elastomer (System 6A), an aluminum-pigmented urethane (System 10), and an aluminum-asphalt coating (System 15). All of the other systems absorbed 1 gram or less. The checking of the acrylic elastomer (System 6A), shown in Figure 11, probably accounts for its higher absorption. The higher absorption on System 10 appears consistent at each of the exposure periods and thus is apparently inherent for this urethane material.

After 9-months of exposure to the weather at Port Hueneme, more than half of the systems gained over 1 gram in weight in the wind-driven rain test, while four of these gained 2 grams or more. Because of the fact that some of these coatings are considered water vapor permeable while others are considered water vapor impermeable, it would appear that the relative increase in water absorption may be more important than the actual amount. However, the data to date do not appear to be sufficiently strong to establish criteria; additional exposure and testing are required.

The samples of PUF systems in which the foam was aged prior to coating (Systems 2-1 through 2-6 and Systems 7-1 through 7-6), were also subjected to the wind-driven-rain test after exposure periods of 2 and 9 months. Results, which are presented in Table 7, do not show any trends and additional exposure will be required.

Impact Resistance

The coating is considered to have failed the impact test when it is ruptured, at which point the weight of the impactor is recorded. This test was run both before samples had been exposed and after they had been exposed for 9 months. Results are presented graphically in Figure 7. The impact test result may be an indicator of the resistance of the coated PUF roofing systems to damage by hailstones and to some extent by foot traffic. Both can cause damage to a system having low impact resistance.

A study of Figure 7 points up several interesting factors. First and perhaps most important is that after 9 months of weathering, the aluminum-asphalt (System 15), the chlorinated rubber (System 11), all of the butyl-hypalons (Systems 3, 4, and 9), the aluminum-pigmented butyl

(System 8), the neoprene-hypalon (System 7), the catalyzed silicone (System 1), hypalon mastic (System 12), and the aluminum-pigmented urethane (System 10) were ruptured by an impactor weight of 200 grams or less. The other hypalon mastics (Systems 5 and 12A) both ruptured at 300 grams (9 months weathering) while one of the silicones (System 2A) did not fail until the weight had reached 400 grams. One of the acrylic elastomers (System 6) failed at 500 grams while the remaining acrylic (System 6A), a moisture-curing silicone (System 2), catalyzed urethane (System 13), and the moisture-curing urethanes (Systems 14 and 14A) had not failed at the maximum weight of 500 grams.

Just how these results compare to "impacts" that a PUF roofing system might reasonably be expected to receive from workmen on a roof or from hailstones is not known at this time. However, it is quite likely that after a minimum of 9 months of weathering, aluminum-asphalts, chlorinated rubber, butyls, butyl-hypalons, and neoprene-hypalon coating systems lack what may be considered a minimum required impact resistance. The silicones, acrylic elastomers and certain urethanes appear to have average to excellent resistance to impact. Additional study and testing of the impact resistance of the coated PUF systems are required in order to quantify and correlate with mechanical damage such as that caused by workmen's shoes and that caused by hailstones.

Tensile Properties of Free Films of the Coating Systems

Free films of the total coating systems, both base coat and topcoat where applicable, were prepared at the same time as the exposure panels. The free films were stripped from the glass plates to which they had been applied and, after curing times of 3, 6, and 12 months under ambient laboratory conditions, were cut to size and tested to failure in tension. Results are presented in Table 8 for tensile strength in grams per square millimeter and elongation in percent. Because of the constraints of time, not all systems were tested at the 3- and 12-month curing periods. However, a sufficient number of the systems were tested at either two consecutive, or all three periods, to determine the effects of aging in the laboratory on tensile strength. While there were some variations, in most cases the tensile strengths increased and the elongation decreased as the exposure time increased. This same trend is also typical of conventional paint systems [5].

Good tensile properties for coating systems for PUF are believed to be of primary importance, because high tensile strength and high elongation insure a coating with good flexibility. Good flexibility is required to enable a coating system to accommodate the rather large expansions and contractions that occur when PUF is subjected to vicious temperature cycling. The following discussion is concerned primarily with tensile property results from the 6-month cure time.

One of the most significant results in Table 8 is the excellent tensile strength of System 13, a catalyzed urethane. The tensile strength for this system, 1,115 gm/mm^2, was considerably higher than for

any of the other systems. The next highest value was 311 gm/mm^2 for System 7, a neoprene-hypalon. The urethanes, neoprene-hypalon, and silicones generally had relatively good tensile strengths while the butyl-hypalons, hypalons, acrylics, and aluminum-asphalts exhibited moderate to poor strengths, some as low as 40 to 50 gm/mm^2.

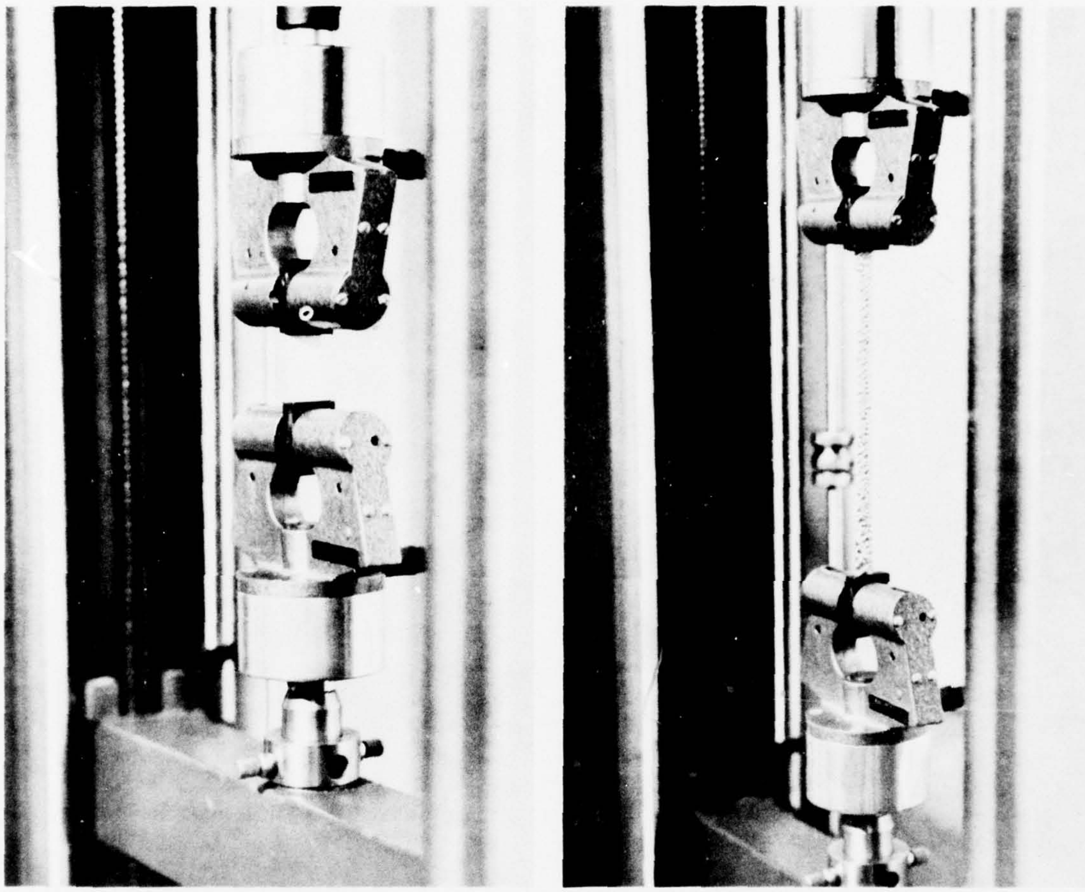
The elongation of System 13 is not quite as high as another urethane (System 10) at the 6-month period. However, after 1 year of curing, System 13 has the highest elongation at 779%. The exceptional elongation of System 13 is illustrated in Figure 19(a) before testing and 19(b) on reaching maximum elongation just before failure. Notice in Figure 19(b), the white topcoat has failed giving the specimen a lacy appearance. The base coat is the backbone of the system. The hypalons, neoprene-hypalon and butyl-hypalons have elongations of 300% to 500%. Elongation of the silicones is not very high. Some of the butyl, butyl-hypalons and chlorinated rubber coatings had elongations less than 100% while elongation of the aluminum-asphalt (System 15) was only 17%.

GENERAL DISCUSSION

In an earlier report [3], it was stated that tensile strength may be more important than elongation with respect to the ability of coated PUF systems to withstand impact damage from objects such as hailstones. It was felt that, because of the dynamic nature of a falling object such as a hailstone impacting on the roof, the tensile strength might be the determining factor as to whether or not the roof was damaged.

On the basis of the results reported in Reference 3, it was suggested as a rule of thumb that coating systems with a tensile strength higher than 300 psi (or 211 gm/mm^2) might withstand damage by hailstones, while those systems with tensile strengths under 300 psi might not. It was hoped that some correlation might be shown between the tensile strength and the impact resistance. However, on the basis of the preliminary information shown here, this does not appear to be the case. It appears that tensile strength, elongation, adhesion and impact resistance are the most important properties with respect to a coating system's performance on PUF. At this early stage in the program, however, the data are too limited to attempt a valid correlation of the laboratory results with the performance results on weathering. Moisture absorption determined by the wind-driven rain test may or may not be a good indicator for determining or predicting early failure, because it appears as though some coatings can be near failure before any appreciable change occurs in the amount of moisture absorption. In any event, it is felt that with additional data it may be possible to develop performance criteria which can be used to specify superior coating systems for use on PUF roofs.

Table 9 ranks the coating systems according to the laboratory tests. All systems have been ranked within each of the five test categories; systems that performed best are ranked first, those next best as



(a) Before testing. (b) Just before failure.

Figure 19. Tensile testing of free film of catalyzed urethane elastomer (System 13).

second, and so on with the poorest performers ranked last. The ranking positions for each system in all five tests were then added and all fifteen systems ranked from first to fifteenth place; these rankings are shown in Table 10. System 13, ranked as No. 1, is considered the best overall performer in the laboratory tests while System 8, ranked as No. 15, is considered the poorest performer.

It is interesting to compare these rankings with the results of performance given in Table 2. When one considers that the checking or cracking in System 2 occurred before exposure and has not become more severe on exposure, this system has been performing quite satisfactorily. Thus the first nine rankings in Table 10 can be rated as excellent in their performance. The eighth system in the ranking, a moisture-curing urethane (System 14A), was rated as excellent after 1 year of exposure at Port Hueneme. However, this system appears to be subject to regressive deterioration and it is expected that, in spite of its excellent physical properties (as measured in the laboratory), severe deterioration will occur within the next year of exposure. The tenth-ranked system in Table 10, System 3, has essentially failed at two of the three sites, while No. 14 and No. 15 rankings (Systems 15 and 8) were rated as very good.

It should be noted that the coating systems in the first nine rankings (actually 10 systems), consisted of urethanes, silicones, a neoprene-hypalon, hypalon mastics and a chlorinated rubber. One acrylic system was included in the top ten rankings and the other in the bottom six. However, four of the six systems ranked last are butyl or butyl-hypalons.

Performance results from the three test sites do show some variations. As expected, the Port Hueneme site appears to be slightly less severe than the other two. It is premature to attempt to differentiate between the relative severities at the China Lake and Pickel Meadows sites. Differences in severities are of course due to differences in climatic conditions. The average monthly weather data for the three sites are given in Appendix C. These data show that (1) the Port Hueneme site is a rather temperate climate with small to moderate annual rainfall, (2) China Lake is a much hotter climate with little rainfall but average minimum temperatures that do drop below freezing, and (3) Pickel Meadows is a colder region with very low average temperature, little rain and considerable snow.

The average temperature differences (difference between average maximum and average minimum) at the three sites during the test period are (1) Port Hueneme about 21^{o}F, (2) China Lake about 33^{o}F and (3) Pickel Meadows about 40^{o}F. The magnitudes of these differences provide an indication of the temperature cycling that occurs at each location; it is this cycling which is so severe on the performance of the coating systems. Although the Pickel Meadows site has the greatest temperature difference, 40 F^{o}versus 33^{o}F for China Lake, it may be that the China Lake site will turn out to be the most severe because the range of average temperatures at China Lake is about 20^{o}F higher than at Pickel Meadows. Higher temperatures cause larger expansion and contraction cycling which an adequate coating system must accommodate without failure.

FLAMMABILITY AND FIRE SAFETY

The following comments and observations are made to emphasize the importance of fire safety, although fire tests of roofing materials were not included in this investigation. Susceptibility to damage by fire is always a potential problem with plastic materials, and PUF systems are no exception. PUF roofing systems should meet the same fire requirements as any other roofing system, and should have fire ratings as given below.

1. Exterior Fire Exposure: Total system, i.e., coating material and urethane foam, should have a UL 790 Class A, B, or C rating.

2. Interior Fire Exposure: NAVFAC Instruction 11320.20 requires that urethane foam component of roofing system shall have a flame spread of 25 or less and a smoke developed rating of 50 or less (when tested in accordance with ASTM E-84 in the same density and thickness as will be used in the actual construction application), with the following exception: compliance with flame spread and smoke developed ratings are not required when PUF roofing system has been tested as a part of a roof construction assembly that has been fire tested and listed as being "Fire Acceptable" by UL or listed as "Class 1 Roof Deck Construction" by FM.

NAVFAC has concluded that the above criteria for interior fire exposure are not applicable when PUF roofing systems are applied to the following types of roof decks:

(1) Poured gypsum or poured concrete.

(2) Nominal 2-inch thick T&G wood plank roof decks (ODASD has provided waiver).

(3) Precast roof deck panels or planks which are FM approved as "Noncombustible Roof Deck Construction."

All but four of the coated PUF roofing systems selected for this investigation had a UL 790 Class A, B, or C rating; the exceptions were Systems 7, 10, 13, and 15. Of the exceptions, Systems 10 and 13 now have variations which enable them to meet these fire requirements.

In recent correspondence with CEL, NAVFAC expressed concern that urethane foam roof systems applied directly to metal roof decks might constitute a serious hazard in the case of a fire originating inside the building, i.e., a PUF roofing system applied directly to the exterior of a metal roof deck might contribute fuel and/or smoke to a fire originating inside the building. CEL believes that the fire safety of PUF roofing systems under these conditions should be established as soon as possible. Since this type of roof deck construction has not been evaluated for this purpose by either Underwriter's Laboratories (UL) or by Factory Mutual (FM), CEL has suggested to NAVFAC that such tests be conducted by both laboratories to clarify the issue. Until these tests are conducted, CEL is not recommending the application of PUF roofing systems directly to metal roof decks.

FINDINGS AND CONCLUSIONS

Findings and conclusions presented below are based on the rather short-term laboratory and field exposure studies, the latter being only 6 months to 2 years duration. Recognizing that 2 years is not a significant length of exposure for evaluating a roofing system, the comments that are made below are tentative and therefore subject to later modification.

1. Granules sprinkled into the wet topcoat (System 1G) provide additional protection against mechanical damage (including impact), weathering, bird pecking, and they also improve general appearance.

2. Manufacturer's instructions should be followed explicitly during application of a PUF roofing system, and every attempt should be made to eliminate or at least minimize solvent pinholing, since pinholes appear to be focal points for incipient coating deterioration.

3. While it is generally considered good practice to apply no more foam in one day than can be overcoated the same day, aging studies indicate that there is no significant loss of adhesion of the coating system until the exposed foam is 48 to 72 hours old.

4. Foam degradation studies indicate that PUF exposed to the weather may degrade at a rate as high as 1/6 inch per year for foam with a density of 2 pcf and 1/9 inch per year for foam with a density of 2.5 pcf.

5. Although all of the laboratory property tests are pertinent, the tensile properties of a given coating system may be most important because they are indicative of its flexibility.

6. Because of the potential for solvent pinholing in a number of these systems, two-coat systems are preferable to one-coat systems.

7. The China Lake and Pickel Meadows exposure sites are considerably more severe than the Port Hueneme site. Because of its higher ambient temperatures, China Lake may prove to be slightly more severe than Pickel Meadows.

8. Based on the preliminary results, the catalyzed urethanes, neoprene-hypalon, silicones, hypalon mastics, chlorinated rubber, and acrylics have better performance characteristics than the butyl, butyl-hypalons, aluminum-asphalt, and a moisture-curing urethane.

RECOMMENDATIONS

Based on both the laboratory and field data reported herein, the following recommendations are made:

1. The following coating systems used over spray-applied PUF systems will give the best results: the silicones (Systems 1, 1G, 2 or 2A), catalyzed urethanes (fire-rated versions of Systems 10 and 13), hypalon mastic (System 5), acrylic elastomer (System 6), or neoprene-hypalon (System 7).

2. PUF roofing systems should have a UL 790 Class A, B, or C rating and should conform to NAVFACINST 11320.20, except when applied over the following types of roof decks:

(a) Poured gypsum or poured concrete.

(b) Nominal 2-inch-thick T&G wood plank roof decks.

(c) Precast roof deck panels or planks which are FM approved as "Noncombustible Roof Deck Construction."

3. No more foam should be applied on a given day than can reasonably be overcoated the same day. If unexpected delays occur, the coating should be applied by no later than the end of the second day after foaming.

4. When the silicones or acrylic are used (Systems 1, 2, or 6), mineral roofing granules should be sprinkled into the wet topcoat to (a) increase abrasion resistance, (b) improve resistance to bird pecking, and (c) improve general appearance.

5. A minimum thickness of 2-1/2 to 3 inches of PUF should be used to meet DOD criteria for energy conservation in roofs (U = 0.05 Btu/hr sq ft ^{o}F).

6. PUF having a density of 2.5 to 3.0 pcf should be used because it is less subject to mechanical damage than lower density foam.

ACKNOWLEDGMENTS

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Appreciation is also expressed to personnel at the Naval Weapons Center, China Lake, California and the Marine Corps Mountain Warfare Training Center, Pickel Meadows, California for cooperating in the exposure of the PUF panels at those sites.

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Table 1. Coating System Descriptions

System Designation and Color	No. of Coats	Dry Film Thickness (mils)	Total (mils)
1 — Catalyzed silicone rubber			
Base coat, medium gray	1	13.5	20.5
Topcoat, cement gray	1	7.0	
1G — Catalyzed silicone rubber with granules			
Base coat, medium gray	1	13.5	20.5
Topcoat, cement gray	1	7.0	
2 — Moisture-curing silicone rubber			
Base coat, light gray	1	5.0	23.5
Topcoat, white	1	18.5	
2A — Moisture-curing silicone rubber			
Base coat, light gray	1	8.5	16.0
Topcoat, white	1	7.5	
3 — Catalyzed butyl-hypalon			
Butyl base coat, black	1	13.0	18.0
Hypalon topcoat, white	1	5.0	
4 — Catalyzed butyl-hypalon			
Catalyzed butyl base coat, tan	1	14.0	21.0
One-component hypalon topcoat, white	1	7.0	
4A — Catalyzed butyl-hypalon			
Catalyzed butyl base coat, tan	1	14.0	21.0
One-component hypalon topcoat, white	1	7.0	
5 — Hypalon mastic			
Hypalon mastic, white	1	—	16.5
6 — Elastomeric acrylic emulsion			
Acrylic emulsion, white	2	—	41.0
6A — Elastomeric acrylic emulsion			
Acrylic emulsion, white	1	—	34.0
7 — Neoprene-hypalon			
Neoprene base coat, black	3	9.0	22.0
Hypalon topcoat, white	2	13.0	
8 — Aluminum-pigmented catalyzed butyl			
Catalyzed butyl, aluminum gray	2	—	26.0

continued

Table 1. Continued

System Designation and Color	No. of Coats	Dry Film Thickness (mils)	Total (mils)
8A — Aluminum-pigmented catalyzed butyl			
Catalyzed butyl, aluminum gray	2	—	26.0
9 — Catalyzed butyl-hypalon			
Catalyzed butyl base coat, black	1	15.5	22.0
One-component hypalon topcoat, white	1	6.5	
10 — Aluminum-pigmented catalyzed urethane elastomer			
Catalyzed urethane elastomer, aluminum	1	—	26.0
11 — Chlorinated rubber			
Chlorinated rubber base coat, gray	1	14.0	26.0
Chlorinated rubber topcoat, white	1	12.0	
12 — Hypalon mastic, white	2	—	33.0
12A — Hypalon mastic, white	2	—	29.0
13 — Catalyzed urethane elastomer			
Catalyzed urethane base coat, aluminum gray	1	15.0	23.5
Catalyzed urethane topcoat, white	1	8.5	
14 — Moisture-curing urethane			
Elastomer, gray	1	—	42.0
14A — Moisture-curing urethane			
Elastomer, gray	2	—	39.0
15 — Fibrated aluminum-asphalt			
Fibrated asphalt, black	1	22.0	44.0
Fibrated aluminum-asphalt, aluminum	1	22.0	

Table 2. Performance Ratings[a] For Coated PUF Roofing Systems Exposed at the Three Sites

System Number and Description	Foam Density (pcf)	Coating Thickness (mils)	Ratings at the Various Exposure Sites[a]												Remarks[b]
			Port Hueneme (years)				China Lake (years)				Pickel Meadows (years)				
			0.5	1	1.5	2	0.5	1	1.5	2	0.5	1	1.5	2	
1 – Catalyzed silicone rubber	2	20.5	E	E	E	E	E	E			E	E			Retains dirt.
1G – Catalyzed silicone rubber with granules	2	20.5	E	E	E		E	E			E	E			Looks very good.
2 – Moisture-curing silicone rubber	2	23.5	VG	VG	VG	VG	VG	VG			E	E			Panels at P.H. and C.L. had light checking or cracking of coating in depressions.
2A – Moisture-curing silicone rubber	2.5	16.0	E	E			E				E				Both 2 and 2A retain dirt on exposure.
3 – Catalyzed butyl-hypalon	2	18.0	VG	G	G	G-P	G	F			E	P-F			Very dense shallow solvent pinholes in top-coat all over panel.
4 – Catalyzed butyl-hypalon	2	21.0	E	E	E	E	E	E			E	E			Very dense shallow solvent pinholes in top-coat all over panel.
4A – Catalyzed butyl-hypalon	2.5	21.0	E	E			E				E				Pinholing not quite as dense as with System 4.
5 – Hypalon mastic	2	16.5	E	E	E	E	E	E			E	E			Dense, shallow pinhead-sized depression in coating.
6 – Elastomeric acrylic emulsion	2	41.0	E	E	E	E	E	E			E	E			Retains dirt.
6A – Elastomeric acrylic emulsion	2	34.0	VG	VG	VG	VG	E	E			E	E			Retains dirt; P.H. panel has very light checking in depressions all over panel.
7 – Neoprene-hypalon	2	22.0	E	E	E	E	E	E			E	E			Medium dense shallow to deep solvent pinholes all over panel.
8 – Aluminum-pigmented catalyzed butyl	2	26.0	E	E	E-VG	VG	E	E			E	G			Very dense shallow solvent pinholes all over panel; pinholes become more obvious with weathering.
8A – Aluminum-pigmented catalyzed butyl	2.5	26.0	E	E			E				E				A few solvent pinholes scattered around panel.
9 – Catalyzed butyl-hypalon	2	22.0	E	E	E	E	E	E			E	E			Dense shallow solvent pinholes all over panel.

continued

Table 2. Continued

System Number and Description	Foam Density (pcf)	Coating Thickness (mils)	Ratings at the Various Exposure Sites[a]												Remarks[b]
			Port Hueneme (years)				China Lake (years)				Pickel Meadows (years)				
			0.5	1	1.5	2	0.5	1	1.5	2	0.5	1	1.5	2	
10 – Aluminum-pigmented catalyzed urethane	2	26.0	E	E	E	E	E	E			E	E			Looks very good, but tended to puddle in low spots.
11 – Chlorinated rubber	2	26.0	E	E	E	E	E	E			E	E			Looks very good.
12 – Hypalon mastic	2	33.0	E	E	E		E	E			E	E			Very dense, shallow to deep solvent pinholes all over panel.
12A – Hypalon mastic	2.5	29.0	E	E			E				E				Little or no pinholing.
13 – Catalyzed urethane	2	23.5	E	E	E		E	E			E	E			Looks very good.
14 – Moisture-curing urethane	2	42.0	G	G–P	P–F		G	P			E	P–F			Dense solvent pinholes ranging from quite small up to 1/16 in. in diameter.
14A – Moisture-curing urethane	2.5	39.0	E	E			E				E				Very few pinholes compared to System 14.
15 – Fibrated aluminum-asphalt	2.5	44.0	E	E			VG				VG				Looks very good.

[a] Overall performance ratings were assigned as follows:
E = Excellent. The system is performing without any noticeable deterioration.
VG = Very good. Only very minor deterioration of the system.
G = Good. Although the PUF roofing system shows deterioration, it is not yet serious.
P = Poor. System deterioration is serious; remedial action will be required in the near future.
F = Failed. Deterioration of the system has advanced to the point of requiring immediate maintenance.

[b] Condition on exposure.

[c] Blank indicates that panel exposure age had not yet reached age shown.

Table 3. Degradation Rates of Uncoated PUF for a Period of 8.3 Months

Foam Density (pcf)	Total Degradation (in.)	Degradation Rate (in./mo)
2.0	0.117[a]	0.014[b]
2.5	0.072	0.009

[a]Average of 3 panels.

[b]Degradation rate = total degradation divided by 8.3.

Table 4. Adhesion Properties of Coatings on PUF Roofing Panels

System Number and Description	Before Exposure		Three Months Rack-Exposure		Nine Months Rack-Exposure	
	Stress (kg/cm^2)	Failure Mode	Stress (kg/cm^2)	Failure Mode	Stress (kg/cm^2)	Failure Mode
1 — Catalyzed silicone rubber	11.1[a]	6[b]	9.9	6	10.4	6
2 — Moisture-curing silicone rubber	9.9	6	9.9	6	10.7	6
2A — Moisture-curing silicone rubber	10.0	6,1	9.2	3,6	10.2	6
3 — Catalyzed butyl-hypalon	7.7	5,3	7.6	3	6.5	5,2
4 — Catalyzed butyl-hypalon	13.0	5,3	12.0	5	12.2	5
5 — Hypalon mastic	20.5	6	18.2	6	18.3	6
6 — Elastomeric acrylic emulsion	13.8	5	14.6	5	17.3	5,6
6A — Elastomeric acrylic emulsion	17.1	6	16.4	6	17.7	6
7 — Neoprene-hypalon	22.0	6	20.1	6	22.6	6
8 — Aluminum-pigmented catalyzed butyl	10.9	5	10.6	5	13.1	5
9 — Catalyzed butyl-hypalon	16.0	5,6,2	16.1	5,6,2	17.1	6
10 — Aluminum-pigmented catalyzed urethane	15.4	6	14.0	6	16.7	6
11 — Chlorinated rubber	18.4	6	15.3	6	17.9	6

continued

Table 4. Continued

System Number and Description	Before Exposure		Three Months Rack-Exposure		Nine Months Rack-Exposure	
	Stress (kg/cm^2)	Failure Mode	Stress (kg/cm^2)	Failure Mode	Stress (kg/cm^2)	Failure Mode
12A — Hypalon mastic	21.4	6	17.2	6	18.9	6
13 — Catalyzed urethane	19.3	1,5	16.5	6,2	18.5	6
14A — Moisture-curing urethane	22.4	6	12.9	6,1	11.0	4,6
15 — Fibrated aluminum-asphalt	16.8	3	14.5	4,5	10.2	4
C-2 — Uncoated Control	11.9	6	13.1	6	8.5	6
C-12 — Uncoated Control	16.7	6	11.5	6	7.9	6

[a] Crosshead speed was 0.5 cm/minute.

[b]
1. Adhesive failure of probe to coating.
2. Adhesive failure between topcoat and base coat.
3. Adhesive failure of coating to foam surface.
4. Cohesive failure in topcoat.
5. Cohesive failure in base coat.
6. Cohesive failure in foam.

Table 5. Adhesion Properties of Coatings on PUF Panels Aged Prior to Coating

System Number and Description	Foam Age Before Coating	Two Months Rack-Exposure		Nine Months Rack-Exposure	
		Stress (kg/cm^2)	Failure Mode	Stress (kg/cm^2)	Failure Mode
Moisture-Curing Silicone Rubber					
2-1	1 hour	8.5[a]	3,6[b]	7.1	3
2-2	3 hours	8.7	3,6	8.7	3,6
2-3	24 hours	7.6	3	7.2	3
2-4	48 hours	6.5	3	7.0	3
2-5	72 hours	5.5	3	4.9	3
2-6	9 days	5.9	3	5.7	3
Neoprene-Hypalon					
7-1	1 hour	22.9	6,4	18.8	6,2
7-2	3 hours	20.0	6,2,4	17.7	6,2
7-3	24 hours	21.6	6,2	18.2	6,2
7-4	48 hours	20.7	6	18.8	6
7-5	72 hours	22.9	6	18.6	6
7-6	7 days	18.9	6	16.9	6

[a] Crosshead speed was 0.5 cm/minute.

[b] For definition of failure code, see footnote b, Table 4.

Table 6. Results of Wind-Driven Rain Tests on Coated PUF Specimens

System Number and Description	Vapor Permeability of Coating	Gain in Weight (grams)			Remarks
		Before Exposure	Three Months Exposure	Nine Months Exposure	
1 – Catalyzed silicone rubber	yes	1.0[a]	0.4[b]	0.2[b]	
2 – Moisture-curing silicone rubber	yes	0.5	0.4	0.2	Coating has several cracks in depressed areas.
2A – Moisture-curing silicone rubber	yes	0.6	0.3	0.2	
3 – Catalyzed butyl-hypalon	no	0.4	0.5	0.9	
4 – Catalyzed butyl-hypalon	no	0.5	0.2	0.2	
5 – Hypalon mastic	no	0.5	0.2	2.2	
6 – Elastomeric acrylic emulsion (2 coats)	yes	0.2	0.6	1.4	
6A – Elastomeric acrylic emulsion (1 coat)	yes	3.4	0.2	2.4	Coating has numerous cracks in depressed areas.
7 – Neoprene-hypalon	moderate	0.8	0.7	1.8	
8 – Aluminum-pigmented catalyzed butyl	no	0.4	0.5	2.0	
9 – Catalyzed butyl-hypalon	no	0.7	1.0	1.7	
10 – Aluminum-pigmented catalyzed urethane	moderate	2.1	1.6	1.9	
11 – Chlorinated rubber	moderate	0.7	0.7	0.4	
12A – Hypalon mastic	no	0.8	0.7	1.6	
13 – Catalyzed urethane	yes	0.8	0.4	0.6	
14A – Moisture-curing urethane	yes	0.4	1.7	2.8	
15 – Fibrated aluminum-asphalt	no	1.9	0.4	0.2	
C-2 Uncoated Control (2.0 pcf)		2.1		3.7	Specimen surface vacuum brushed before testing to remove degraded foam.
C-12 Uncoated Control (2.5 pcf)			4.6[c]	7.7	

[a] Exposed to wind-driven rain test for 7 hours.

[b] Exposed to wind-driven rain test for 24 hours.

[c] Sample exposed only 2 months.

Table 7. Results of Wind-Driven Rain Testing of Coated PUF Panels Weathered Before Coating

System Number and Description	Foam Age Before Coating	Gain in Weight (grams)	
		Two Months Exposure	Nine Months Exposure
Moisture-Curing Silicone Rubber			
2-1	1 hour	0.5[a]	1.6
2-2	3 hours	0.7	1.8
2-3	24 hours	0.7	1.5
2-4	48 hours	1.0	0.9
2-5	72 hours	2.0	1.9
2-6	9 days	1.0	1.0
Neoprene-Hypalon[b]			
7-1	1 hour	1.8	1.6
7-2	3 hours	1.4	1.6
7-3	24 hours	2.0	1.6
7-4	48 hours	1.4	1.1
7-5	72 hours	1.4	1.0
7-6	9 days	1.8	1.7

[a] Exposed to wind-driven rain test for 24 hours.

[b] All coatings on panels of this system exhibited dense solvent pinholing.

Table 8. Tensile Test Results of Free Films of Coating Systems for PUF[a]

System Number and Description	Cure Time[b]						Remarks
	3 Months		6 Months		12 Months		
	Maximum Tensile Strength (gm/mm^2)	Elongation (%)	Maximum Tensile Strength (gm/mm^2)	Elongation (%)	Maximum Tensile Strength (gm/mm^2)	Elongation (%)	
1 – Catalyzed silicone rubber	241.4	121	218.5	97	208.7	91	
2 – Moisture-curing silicone rubber			250.8	199	292.0	256	
2A – Moisture-curing silicone rubber	283.6	230	307.4	236			
3 – Catalyzed butyl-hypalon			124.4	308	138.8	235	
4 – Catalyzed butyl-hypalon			89.1	77	105.4	76	
5 – Hypalon mastic			159.7	489			
6 – Elastomeric acrylic emulsion			81.2	218	114.4	190	
6A – Elastomeric acrylic emulsion			73.6	122	112.4	104	
7 – Neoprene-hypalon			311.7	311	386.6	251	
8 – Aluminum-pigmented catalyzed butyl	33.1	92	41.1	70			
9 – Catalyzed butyl-hypalon			108.0	183	164.0	128	
10 – Aluminum-pigmented catalyzed urethane	174.7	738	225.5	776	164.9	725	
11 – Chlorinated rubber	185.3	118	188.8	88	206.0	104	
12A – Hypalon mastic	39.8	171	49.3	174			
13 – Catalyzed urethane	1054.9	698	1115.0	660	2040.0	779	Topcoat failed first giving lacy appearance (see Figure 6).
14A – Moisture-curing urethane	173.2	432	174.4	358			
15 – Fibrated aluminum-asphalt	55.8	57	86.5	17			

[a] Speed of testing was 0.5 cm per minute.

[b] Length of time that free coating films cured under ambient laboratory conditions before testing.

Table 9. Ranking of Coating Systems and Coated PUF Systems Within Each Test Method

System Number and Description

Ranking	Adhesion	Tensile Strength	Elongation	Impact Resistance	Moisture Absorption
1	7 – Neoprene-hypalon	13 – Urethane	10 – Urethane	2A – Silicone	1 – Silicone
1	–	–	–	6A – Silicone	2 – Silicone
1	–	–	–	13 – Urethane	2A – Silicone
1	–	–	–	14A – Urethane	4 – Butyl-hypalon
1	–	–	–	–	15 – Aluminum-asphalt
2	12A – Hypalon mastic	7 – Neoprene-hypalon	13 – Urethane	6 – Acrylic	11 – Chlorinated rubber
3	13 – Urethane	2A – Silicone	5 – Hypalon mastic	2 – Silicone	13 – Urethane
4	5 – Hypalon mastic	2 – Silicone	14A – Urethane	5 – Hypalon mastic	3 – Butyl-hypalon
4	–	–	–	12A – Hypalon mastic	–
5	11 – Chlorinated rubber	10 – Urethane	7 – Neoprene-hypalon	1 – Silicone	6 – Acrylic
5	–	–	–	3 – Butyl-hypalon	–
5	–	–	–	4 – Butyl-hypalon	–
5	–	–	–	8 – Butyl	–
5	–	–	–	11 – Chlorinated rubber	–
6	6A – Acrylic	1 – Silicone	3 – Butyl-hypalon	10 – Urethane	12A – Hypalon mastic
6	–	–	–	7 – Neoprene-hypalon	–
6	–	–	–	9 – Butyl-hypalon	–
7	6 – Acrylic	11 – Chlorinated rubber	2A – Silicone	15 – Aluminum-asphalt	9 – Butyl-hypalon
8	9 – Butyl-hypalon	14A – Urethane	6 – Acrylic	–	7 – Neoprene-hypalon
9	10 – Urethane	5 – Hypalon mastic	2 – Silicone	–	10 – Urethane
10	8 – Butyl	3 – Butyl-hypalon	9 – Butyl-hypalon	–	8 – Butyl
11	4 – Butyl-hypalon	9 – Butyl-hypalon	12A – Hypalon mastic	–	5 – Hypalon mastic
12	14A – Urethane	4 – Butyl-hypalon	6A – Acrylic	–	6A – Acrylic
13	2 – Silicone	15 – Aluminum-asphalt	1 – Silicone	–	–
14	1 – Silicone	6 – Acrylic	11 – Chlorinated rubber	–	14A – Urethane
15	2A – Silicone	6A – Acrylic	4 – Butyl-hypalon	–	–
15	15 – Aluminum-asphalt	–	–	–	–
16	3 – Butyl-hypalon	12A – Hypalon mastic	8 – Butyl	–	–
17	–	8 – Butyl	15 – Aluminum-asphalt	–	–

Table 10. Consolidated Ranking of Coated PUF Roofing Systems Based on Table 9

Ranking	System Number	Description
1	13	Urethane
2	7	Neoprene-hypalon
3	2A	Silicone
4	2	Silicone
4	10	Urethane
5	5	Hypalon mastic
6	11	Chlorinated rubber
7	6	Acrylic
8	14A	Urethane
9	1	Silicone
9	12A	Hypalon mastic
10	3	Butyl-hypalon
11	9	Butyl-hypalon
12	4	Butyl-hypalon
13	6A	Acrylic
14	15	Aluminum-asphalt
15	8	Butyl

Appendix A

FOAM AND COATING MATERIAL NAMES AND SOURCES

PUF MATERIAL

Proprietary Name	Source
CPR Upjohn 485-2 (2 pcf) CPR Upjohn 485-2.5 (2.5 pcf)	CPR Division The Upjohn Company 555 Alaska Avenue Torrance, California 90503

COATING MATERIALS

Coating System No.	Source
1. Silicone weather coatings 3308/W501C base coat, medium gray 3304/W3007C topcoat, cement gray	Silicone Products Department General Electric Company Waterford, New York 12188
2. 3-5000 Construction Coating Gray base coat White topcoat	Dow Corning Corporation Midland, Michigan 48640
3. U. S. Polymeric PC-8105 butyl base coat PC-8204 hypalon topcoat	U. S. Polymeric 700 East Dyer Santa Ana, California 92707
4. Elastron Elastron No. 858 butyl base coat Elastomir No. 35 hypalon topcoat	United Coatings 1130 E. Sprague Ave. Spokane, Washington 99202
5. Monolar mastic (hypalon) No. 60-36	Foster Division Amchem Products, Inc. Ambler, Pennsylvania 19002
6. Diathon (acrylic elastomer)	United Coatings 1130 E. Sprague Ave. Spokane, Washington 99202

Coating System No.	Source
7. Gaco-Flex N-118 neoprene base coat H-10 hypalon topcoat	Gates Engineering Company Wilmington, Delaware
8. Vapalon (butyl) No. 6126 Aluminum-gray	Exxon Chemical Company USA 8230 Stedman Street Houston, Texas 77029
9. Chem-Elast 5011 butyl base coat 5501 hypalon topcoat	PlasChem Coatings Eagle-Picher Industries, Inc. 6300 Bartner Industrial Drive St. Louis, Missouri 63130
10. Roof-Flex (urethane) Aluminum 155	Carboline Roofing Products Division 350 Hanley Industrial Ct. St. Louis, Missouri 63144
11. Elastomeric Roof Coating 830-11 (chlorinated rubber)	The FlintKote Company 480 Central Avenue East Rutherford, New Jersey 07073
12. Gaco-Flex Hypalon H-2500	Gaco-Western, Inc. P. O. Box 88698 Seattle, Washington 98188
13. Weather/Flex Plus Irathane 300 base coat Irathane 394 topcoat	Irathane Systems Industrial Park Hibbing, Minnesota 55746
14. Elasto-Deck Elasto-Deck 5001	Pacific Polymers 15801 Moran Street Unit E Westminster, California 42683
15. Alumanation Permaroof base coat Alumanation 301 topcoat	Republic Powdered Metals 2628 Pearl Road Medina, Ohio 44256

Appendix B

RESULTS OF COATING ANALYSIS

System and Description	Weight/ Gallon (lb)	Specific Gravity (g/ml)	Viscosity (Kreb units)	Non-Volatile Solids (%)	Pigment (%)	Non-Volatile Vehicle (%)
1. General Electric Silicone 3308, base coat 3304, top coat	11.1 11.1	1.32 1.33	124 too thick	80.47 81.78	52.70 53.86	27.77 27.91
2. Dow Corning Silicone 3-5000, base and top coats	9.8	1.18	93	73.32	37.92	35.40
3. U. S. Polymeric, PC-8105, butyl base coat PC-8204, hypalon top coat	8.8 8.1	1.06 0.97	55 61	44.49 26.42	29.56 10.87	14.93 15.55
4. United Coatings Elastron 858, butyl base coat 35, hypalon top coat	9.1 10.18	1.08 1.20	106 95	57.31 49.25	42.75 31.55	14.56 17.69
5. Amchem Products 60-36, hypalon	9.02	1.08	too thick	43.50	35.32	8.18
6. United Coatings Diathon acrylic	11.73	1.41	104	71.84	41.02*	30.81
7. Gates Engineering Gaco-Flex N-118, butyl base coat H-10, hypalon top coat	8.33 7.79	1.00 0.98	90 88	31.90 28.08	17.35 6.89	14.54 21.19

continued

Appendix B. Continued

System and Description	Weight/ Gallon (lb)	Specific Gravity (g/ml)	Viscosity (Kreb units)	Non-Volatile Solids (%)	Pigment (%)	Non-Volatile Vehicle (%)
8. Exxon Chemical Vapalon 6126, butyl base coat, part AA, 6126, butyl top coat	11.00 9.25	1.32 1.02	100 101	49.96 59.38	40.59 36.79	9.37 22.59
9. PlasChem Chem-Elast 5501, butyl base coat 5011, hypalon top coat	7.5 9.95	0.90 1.19	53 too thick	37.09 47.44	9.11 37.54	27.98 9.91
10. Carboline Roof-Flex urethane 155, component A 155, component B	7.98 8.62	0.96 1.03	54 86	40.85 79.08	16.82 clear	24.03
11. Flintkote 830-11 chlorinated rubber	9.68	1.16	120	50.96	35.61	15.35
12. Gaco-Western Gaco-Flex H-2500 hypalon	9.26	1.11	too thick	52.78	34.24	18.54
13. IRATHANE Weather/Flex 300 base coat	8.17	0.98	92	70.97	clear	
curing agent	8.26	0.99	63	39.94	13.93	26.02
394, top coat, part A	8.01	0.96	53	40.69	clear	55.64
394, top coat, part B	12.91	1.55	too thick	95.70	40.07	
14. Pacific Polymers Elasto-Deck 5001, urethane	9.71	1.16	too thick	81.19	23.04	58.15

continued

Appendix B. Continued

System and Description	Weight/ Gallon (lb)	Specific Gravity (g/ml)	Viscosity (Kreb units)	Non-Volatile Solids (%)	Pigment (%)	Non-Volatile Vehicle (%)
15. Republic Powdered Metals Permaroof, fibrated asphalt base coat Alumanation, aluminum-asphalt top coat	8.16 8.43	0.98 1.01	too thick too thick	66.40 43.68	16.36 30.43	50.04 13.25

*Ash.

Appendix C

AVERAGE MONTHLY WEATHER DATA

Weather data obtained from monthly National Oceanic and Atmospheric Administration Publication, "Climatological Data."

Table C-1. Average Monthly Weather Data, Port Hueneme, California[a]

Month	Temperature				Precipitation	
	Average Maximum	Average Minimum	Average	Degree Days	Total (in.)	Snow (in.)
1974						
Mar	64.9	47.7	56.3	264	3.10	0.0
Apr	69.9	47.0	58.5	189	0.17	0.0
May	70.3	52.8	61.6	103	trace	0.0
Jun	73.6	55.6	64.6	29	0.00	0.0
Jul	77.8	58.3	68.1	7	0.01	0.0
Aug	76.8	59.2	68.0	0	0.00	0.0
Sep	75.0	56.9	66.0	24	0.00	0.0
Oct	73.8	53.7	63.8	53	0.36	0.0
Nov	73.4	47.5	60.5	154	0.00	0.0
Dec	67.6	43.3	55.5	285	2.75	0.0
1975						
Jan	69.8	42.7	56.3	278	0.00	0.0
Feb	64.3	43.2	53.8	305	0.04	0.0
Mar	64.5	45.6	55.1	304	1.53	0.0
Apr	65.7	44.7	55.2	287	0.93	0.0
May	69.2	50.3	59.8	154	0.00	0.0
Jun	70.8	55.3	63.1	57	0.04	0.0
Jul	75.7	57.4	66.6	9	0.00	0.0
Aug	76.2	58.0	67.1	5	0.00	0.0
Sep	76.1	57.9	67.0	6	trace	0.0
Oct	74.3	50.7	62.5	101	0.38	0.0
Nov	71.9	47.0	59.5	187	0.01	0.0
Dec	68.4	42.8	55.6	287	0.00	0.0
1976						
Jan	72.5	43.7	58.1	229	0.00	0.0
Feb	67.6	44.3	56.0	256	3.64	0.0
Mar	69.1	44.3	56.7	1.5	1.16	0.0

[a]Weather data obtained at nearby Oxnard, California, elevation 49 feet.

Table C-2. Average Monthly Weather Data, China Lake, California[a]

Month	Temperature				Precipitation	
	Average Maximum	Average Minimum	Average	Degree Days	Total (in.)	Snow (in.)
1974						
Mar	71.6	39.6	55.6	278	1.14	trace
Apr	77.3	39.4	58.4	196	0.27	0.0
May	89.5	53.6	71.6	38	0.08	0.0
Jun	100.6	62.2	81.4	0	0.00	0.0
Jul	101.6	67.3	84.5	0	0.52	0.0
Aug	100.3	63.2	81.8	0	0.44	0.0
Sep	98.5	59.9	79.2	0	0.11	0.0
Oct	81.4	50.3	65.9	62	0.00	0.0
Nov	68.7	35.2	52.0	385	0.19	0.0
Dec	57.1	28.7	42.9	671	0.63	0.0
1975						
Jan	61.0	26.5	43.8	652	0.00	0.0
Feb	63.7	31.9	47.8	476	0.00	0.0
Mar	66.8	36.0	51.4	414	0.00	0.0
Apr	68.9	37.5	53.2	347	0.29	0.0
May	87.6	50.7	69.2	58	0.00	0.0
Jun	97.8	60.1	79.0	0	0.00	0.0
Jul	102.7	64.7	83.7	0	0.00	0.0
Aug	100.3	61.5	80.9	0	0.00	0.0
Sep	96.1	59.5	77.8	0	0.95	0.0
Oct	80.9	45.2	63.1	144	0.00	0.0
Nov	68.6	33.1	50.9	419	0.00	0.0
Dec	65.3	30.1	47.7	528	0.00	0.0
1976						
Jan	64.5	28.0	46.3	572	0.00	0.0
Feb	65.8	34.8	50.3	419	3.03	0.0

[a]Weather data obtained at nearby Inyokern, California, elevation 2,440 feet.

Table C-3. Average Monthly Weather Data, Pickel Meadows, California[a]

Month	Temperature				Precipitation	
	Average Maximum	Average Minimum	Average	Degree Days	Total (in.)	Snow (in.)
1974						
Mar	52.3	20.9	36.6	873	0.00	10.0
Apr	57.8	19.1	38.5	791	0.00	2.0
May	67.8	27.8	47.8	525	0.00	2.0
Jun	79.4	34.0	56.7	241	0.23	0.0
Jul	80.5	41.1	60.8	129	1.36	0.0
Aug	80.1	35.5	57.8	218	0.83	0.0
Sep	79.4	27.4	53.4	340	0.00	0.0
Oct	65.0	21.8	43.4	661	1.18	3.0
Nov	53.6	18.8	36.2	859	0.50	4.0
Dec	43.9	10.8	27.4	1,158	0.00	7.0
1975						
Jan	48.6	9.3	29.0	1,117	0.00	3.0
Feb	42.0	11.4	26.7	1,064	0.00	38.0
Mar	46.4	18.8	32.6	997	0.00	30.2
Apr	47.5	17.9	32.7	959	0.00	12.0
May	64.9	23.9	44.4	631	0.10	2.0
Jun	73.0	33.0	53.0	355	0.09	trace
Jul	82.3	38.7	60.5	141	0.20	0.0
Aug	79.3	33.6	56.5	261	1.04	0.0
Sep	77.6	31.9	54.8	299	0.60	0.0
Oct	63.2	21.5	42.4	693	0.00	0.5
Nov	53.2	12.3	32.8	961	0.00	1.5
Dec	52.2	10.0	31.1	980	0.03	2.0
1976						
Jan	53.2	5.2	29.2	1,103	—	2.5
Feb	47.3	11.1	29.2	1,030	0.95	21.0
Mar	50.7	12.2	31.5	1,035	—	4.0

[a]Weather data obtained at nearby Bridgeport, California, elevation 6,560 feet.

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NAVAL FACILITY PWO, Brawdy Wales UK; PWO, Cape Hatteras, Buxton NC; PWO, Centerville Bch, Ferndale CA; PWO, Guam; PWO, Lewes DE
NAVCOASTSYSLAB Code 423 (D. Good), Panama City FL; Code 710.5 (J. Mittleman); Code 710.5 (J. Quirk); Library
NAVCOMMSTA CO (61E); PWO, Fort Amador Canal Zone
NAVCOMMUNIT Cutler/E. Machias ME (PW Gen. For.)
NAVFACENGCOM Code 0433B; Code 0451; Code 04B3; Code 04B5; Code 081B; Code 101; Code 1023 (M. Carr); Code 104; LANTDIV (J.L. Dettbarn) Norfolk, VA.; PC-22 (E. Spencer)
NAVHOSP LT R. Elsbernd, Puerto Rico
NAVOCEANO Code 1600; Code 3412 (J. DePalma), Washington DC
NAVPHIBASE Code S3T, Norfolk VA; OIC, UCT 1
NAVREGMEDCEN PWO; PWO Newport RI
NAVSECGRUACT PWO, Edzell Scotland; PWO, Puerto Rico
NAVSHIPYD Code 440, Norfolk; Code 450, Charleston SC; Library, Portsmouth NH; PWO
NAVSTA CO; CO; Engr. Dir., Rota Spain; Maint. Cont. Div., Guantanamo Bay Cuba; Maint. Div. Dir/Code 531, Rodman Canal Zone; PWD/Engr. Div, Puerto Rico; PWO, Keflavik Iceland; PWO, Puerto Rico; ROICC, Rota Spain
NAVSUPPACT Plan/Engr Div., Naples Italy
NAVSUREWPNCEN PWO, White Oak, Silver Spring, MD
NAVWPNCEN PWO (Code 70), China Lake CA
NAVWPNENGSUPPACT Code ESA-733, Washington DC
NAVWPNSTA Maint. Control Dir., Yorktown VA; PWO
NAS Code 183, Dir Engr Div..; Code 18700, Brunswick ME; Code 6234 (G. Trask), Point Mugu CA; PWD, Maintenance Control Dir., Bermuda
NATIONAL BUREAU OF STANDARDS B-348 BR (Dr. Campbell), Washington DC
NATL RESEARCH COUNCIL Naval Studies Board, Washington DC
NAVACT PWO, London UK
NAVACTDET PWO, Holy Lock UK
NAVBASE Code 111 (A. Castronovo), Philadelphia PA
NAVCOMMSTA PWO
NAVCONSTRACEN CO (CDR C.L. Neugent), Port Hueneme, CA
NAVENVIRHLTHCEN OIC, Cincinnati OH
NAVFACENGCOM - CHES DIV, Code 101; Code 402 (R. Morony); Code 403 (H. DeVoe); Code FPO-1SP (Dr.

Lewis); Code FPO-1T3 (Mr. Scola), Washington DC; *Contracts*, ROICC, Annapolis MD
NAVFACENGCOM - LANT DIV. Code 10A, Norfolk VA; RDT&ELO 09P2, Norfolk VA
NAVFACENGCOM - NORTH DIV. (Boretsky); Code 09P (LCDR A.J. Stewart); Code 1028, RDT&ELO, Philadelphia PA; Code 114 (A. Rhoads); ROICC, Contracts, Crane IN
NAVFACENGCOM - PAC DIV. Code 402, RDT&E, Pearl Harbor HI; Commanders
NAVFACENGCOM - SOUTH DIV. Code 90, RDT&ELO, Charleston SC; Dir., New Orleans LA; ROICC (LCDR R. Moeller), Contracts, Corpus Christi TX
NAVFACENGCOM - WEST DIV. 102; 112; 408, San Bruno CA; AROICC, Contracts, Twentynine Palms CA; AROICC, Point Mugu CA; Codes 09PA; 09P/20
NAVFACENGCOM CONTRACTS Bethesda, Design Div. (R. Lowe) Alexandria VA; Dir, Eng. Div., Exmouth, Australia; Eng Div dir, Southwest Pac, PI; OICC/ROICC, Balboa Canal Zone; ROICC (LCDR J.G. Leech), Subic Bay, R.P.; ROICC, Diego Garcia Island; ROICC, Pacific, San Bruno CA; TRIDENT (CDR J.R. Jacobsen), Bremerton WA 98310
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NAVRADRECFAC PWO, Kami Seya Japan
NAVSCOLCECOFF CO, Code C44A
NAVSEASYSCOM Code SEA OOC
NAVSHIPYD Code 202.4, Long Beach CA; Code 202.5 (Library) Puget Sound, Bremerton WA; Code Portsmouth NH
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NAVSUPPACT AROICC (LT R.G. Hocker), Naples Italy
NAVWPNSUPPCEN PWO
NAS CO, Guantanamo Bay Cuba; Code 114, Alameda CA; Code 18E (ENS P.J. Hickey), Corpus Christi TX; OIC, CBU 417, Oak Harbor WA; PWD (ENS E.S. Agonoy), Chase Field, Beeville TX; PWD (M.B. Trewitt), Dallas TX; PWO (M. Elliott), Los Alamitos CA
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NAVCOASTSYSLAB CO, Panama City FL
NAVCOMMSTA PWO, Norfolk VA
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NAVFACENGCOM Code 0453 (D. Potter); Code 1023 (T. D. Stevens), Alexandria VA
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NAVPETRES Director, Washington DC
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NAVSHIPYD CO Marine Barracks, Norfolk, Portsmouth VA; Code 400.03; Code 453 (H. Clements), Vallejo CA; Code 453 (Util. Supr), Vallejo CA; L.D. Vivian; PWD (Code 400), Philadelphia PA; PWD (LT N.B. Hall), Long Beach CA
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NAVXDIVINGU LT A.M. Parisi, Panama City FL
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NCBU 411 OIC, Norfolk VA
NCR 20, Commander
NMCB 133 (ENS T.W. Nielsen); 5, Operations Dept.; 74, CO; Forty, CO; THREE, Operations Off.
NRL Code 8441 (R.A. Skop), Washington DC
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